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Statistical Risk Analysis for Determining Best Available and Safest Technology (BAST)

Final Report

Massachusetts Institute of Technology, Center for Policy Alternatives

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FOREWORD

This is the final report of a project supported by the Technology Assessment and Research Program of the Minerals Management Service, U.S. Department of the Interior, through a contract from the Sandia National Laboratories to the Massachusetts Institute of Technology, Contract Number #50-1610, as amended. The principal investigator was Christopher T. Hill, formerly Senior Research Associate at MIT.

The findings and opinions expressed herein are those of the authors and do not represent the views of the Massachusetts Institute of Technology, Sandia National Laboratories, the Minerals Management Service, the U.S. Department of the Interior, or the current employers of the authors: Worcester Polytechnic Institute (F.R. Tuler), and the Congressional Research Service of the Library of Congress (C.T. Hill and D.W. Cheney).

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ACKNOWLEDGMENTS

We should like to acknowledge the support of a large number of people in carrying out this project. Among those who were especially helpful to us were our sponsors and contract monitors: from the Minerals Management Service, John B. Gregory and Charles E. Smith, and from Sandia National Laboratories, Henry Dodd and Karen Grubbe. Among the many other staff of MMS who assisted us with information, insights and their time were Richard Giangerelli, Price MacDonald, Jane Roberts, Larry Pease, Richard Ensele, and Bud Danenburger.

During January 1983, we were privileged to be able to interview a number of individuals in government agencies, industry, and trade unions in the United Kingdom and Norway regarding offshore risk management in those nations. Two people were especially helpful in recommending people for us to see and in arranging for interviews: Jan Erik Vinnem of the Norwegian Institute of Technology in Trondheim, and John S. Austin of the Petroleum Engineering Division of the U.K. Department of Energy.

It is only appropriate that we also thank the many others who met with us in Europe. (Their positions and addresses appear in the Appendix.) In the United Kingdom we interviewed Neville Mansfield, John Austin, and Brian Hindley of the Department of Energy; Brian Krause of Reliability Consultants, Ltd.; David Slater of Technica; Michael Ferrow and Peter MacDonald of Conoco, U.K.; Neville Rendall of Shell U.K.; Edward van Duyvenbode and Terry Locke of Shell International, the Hague; Anthony Read and Struan Wilson of the Exploration and Production Forum; Brian Burnett of British Gas; Bill Reid of the Transport and General Workers Union; Blyth McNaughton of Robert Gordon's Institute of Technology, Aberdeen; and several offshore workers with whom we spent a pleasant Saturday afternoon in a pub in Aberdeen.

We were equally fortunate to talk with a number of persons in Norway, including: Lars A. Myhre of the Norwegian Oil and Petrochemical Workers Union; Oystein Berg of the Norwegian Petroleum Directorate; Torkell Gjerstand of Elf Aquitane Norge; Jan Erik Karlsen, Robert Ryall, Trygoe Haye, Svend Otto Remoe, and Tor Tonnessen of the Rogalands Research Institute; Paul Wienecke and Christian Hvam of Statoil; Egil Wulff of the Norwegian Ship Research Institute; Stein Jensen and Roar Andersen of SINTEF; Gudmund Engen of Aker Engineering; Arne Selvik of the Institute of Industrial Economics and Bjorn Basberg of the Norwegian School of Economics and Business Administration, Bergen; Tormod Rodsten and Olav Sivertsen of the Secretariat for Safety and Working Environment Offshore, Ministry of Local Government and Labor; Bjarne Hope and Per Johannessen of Bedriftsradgivning (consultants); Endre Bjordal and H.J. Kraft Johanssen of Norsk Hydro; Morten Sorum, Jan Reier Huse, Svein Fjeld, and Jan Wiborg of Det Norske Veritas; and Hans Skoie, Norwegian Research Council for Science and the Humanities.

We also had the opportunity to consult with a large number of people in the U.S. during the course of this project. Among those who were especially helpful were Hyla Napadensky, Chairperson of the National Research Council Committee on Outer Continental Shelf Safety Information and Analysis, Charles Bookman of the National Research Council; Peter Marshall of Shell Oil; Robert Bea of PMB Associates; Magne Torhaug of Det Norske Veritas, Houston; and Gerald LaRocque and Krishna Mudan of Arthur D. Little, Inc. We were also greatly assisted by colleagues at MIT, including: C. Chryssostomidis, Judith Kildow, Carolyn Heising-Goodman, Jerome Milgram, Greg Becker, and Norman Rasmussen. Finally, we express our appreciation to Kathy Thurmond who served ably as our staff assistant during most of this project.

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CHAPTER 1

INTRODUCTION

1.1 PURPOSE OF THE STUDY

Oil and gas exploration and recovery on the outer continental shelf are very hazardous activities, even when they are designed and managed with the utmost care. Controlling safety and environmental hazards offshore has become increasingly important as activities have been undertaken in more hostile regions of the sea where, for example, water depths are greater, temperatures are lower, icing is common, and storms are more violent and less predictable. Similarly, hazard management has become increasingly important in fields that are much further from shore and that often have high and unpredictable formation pressures.

The more extreme environments now under development require the use of more innovative and ambitious technologies whose performance is more uncertain than the performance of technologies used in earlier phases of the offshore industry. Critical elements of the new technologies, such as drilling platforms, are often not simply extensions of land-based technologies, nor are they evolutionary modifications of the technologies used in more benign offshore conditions. Furthermore, typical platforms for hostile, deep-water environments are much larger and more expensive than those used in the Gulf of Mexico. Thus, the combination of hostile environments, uncertain technologies, and large scale operations poses new risks with potentially greater consequences for workers, the environment, and investors.

Everyone concerned with offshore operations wants better ways to anticipate and cope with their hazards. Designers, builders, operators, owners, insurers, workers, regulators, and neighbors would all prefer that the risks associated with these technologies be reduced to the lowest levels that can be achieved at reasonable costs. At the same time, however, the costs and benefits of improved offshore safety management do not fall equally on each of these groups. As a consequence, the degree of risk that one group would find acceptable is often felt to be too low or too high by others, with the result that reasonable people often disagree about the exact nature and degree of regulation of offshore activities that is necessary or desirable. Such disagreements can not be resolved by appeal to cost/benefit analysis that arbitrarily combines the costs and benefits of regulation regardless of where they fall. Instead, other approaches to regulatory decision-making are needed to help each party to a decision understand what that decision means to them.

One relatively new and promising approach to identifying, analyzing, and managing the hazards of technological projects is probabilistic <u>risk analysis</u>. As we use the phrase in this report, risk analysis encompasses a series of techniques that are used to systematically identify and analyze the ways in which engineered systems can fail to perform the tasks for which they were designed. Prominent among these techniques are various methods of <u>engineering risk analysis</u> including failure modes and effects analysis, hazard and operability studies, and fault and event tree methods. Each of these methods is designed to address complex engineered systems made up of distinct elements so as to analyze how a failure of any one of the elements might lead to undesirable consequences, or conversely to determine how certain types of undesirable events might be initiated by failures of one or more of the elements.

For purposes of this report, risk analysis also encompasses two other classes of analytical methods: <u>structural reliability analysis</u> and <u>chemical risk assessment</u>. The former is a set of techniques used to estimate how complex mechanical structures made of imperfect material elements and connections will respond to externally-applied forces that vary randomly in time. The latter is a set of procedures used to identify and analyze the risks that exposures to chemical substances pose to health and the environment. Each of these classes of probability-based analytic techniques shows promise for use in managing offshore safety and environmental risks.

The main purpose of this study is to examine the possibilities for, and limitations of, using risk analysis in managing offshore hazards. It is focused especially on such use by the Minerals Management Service (MMS[1]) of the U.S. Department of the Interior as it fulfills its mandates to ensure that offshore petroleum resources are developed with due concern for the safety of workers, for the preservation of the natural environment, and for the maintenance of alternative uses of the nation's ocean resources.

In addition to the examination of the potential use of risk analysis, this study has also examined how the current U.S. system of offshore regulation might be modified to take advantage of new approaches to the management of technological risks. This part of the project arose from the realization that risk analysis has facilitated the use in other countries of alternative approaches to offshore safety management that offer certain potential advantages over aspects of the approaches now in use in the United States.

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[1] The MMS leases Federally-owned offshore lands for the recovery of minerals, including oil and gas. In cooperation with other Federal agencies such as the Environmental Protection Agency (EPA) and the Coast Guard, MMS is responsible for seeing that all applicable laws and regulations regarding health, safety and environment are followed by its leaseholders. In addition, MMS can require, through lease stipulations, that offshore activities comply with other rules and orders that it establishes for these purposes.

1.2 APPROACH OF THE STUDY

We considered four sets of experiences with risk analysis that should be helpful in deciding on what role it might play in the programs and decisions of the MMS. These four sets of experiences were: (1) use of risk analysis in the offshore regulatory agencies of other countries, especially Norway and the United Kingdom, (2) use of risk analysis in U.S. regulatory agencies that have offshore responsibilities, including the MMS, (3) use of risk analysis in other industries, and (4) use of risk analysis in firms that are active in offshore development in the U.S. We emphasized items (1) and (2). In addition to a review of the literature and discussions with government and industry representatives in the United States, the study included a two-week round of visits to the United Kingdom and Norway for interviews with government, industry, trade union, and academic experts.

The consideration of alternative approaches to offshore regulation using formal risk analysis was based on a comparative analysis of the regulatory systems of the U.S., the United Kingdom and Norway, and on analogies between the offshore regulatory regime and the systems of risk management in use for such technologies as nuclear power, civilian aviation, and chemical manufacturing. The options for redesign of the offshore safety management system we considered are limited to those that would take greater advantage of formal decision-making techniques, such as risk analysis. This has not been a study of the costs and benefits of offshore safety and environmental regulations, individually or in the aggregate, nor has it been an evaluation of the regulatory system now in place.

1.3 THE NATURE OF OFFSHORE RISKS

Offshore oil and gas operations present a wide array of risks that range over different categories of hazard, that range from the chronic and routine to the rare but catastrophic, and that affect different groups of people and economic interests in widely different ways. This set of risks is among the most complex and diverse of those of any technology in use today.

In considering the potential role of risk analysis in the management of offshore risks, it is useful to categorize those risks with respect to several of their characteristics in order to understand their origins and their implications for the kinds of information needed to make risk management decisions about them. The next few sections examine some of these characteristics.

1.3.1 Categories of Offshore Risks

Offshore hazards can cause worker injuries and loss of life; damage to the natural environment, including the loss of the productivity of regions dedicated to fishing and to collection of bottom-living shell fish; damage to physical property such as equipment, platforms, pipelines, and vessels; and the loss of access to the undersea energy resource. Each of these types of damage is of concern to owners and operators of offshore installations, to workers, to regulatory authorities, to other industries that depend on the ocean's productivity, to insurance underwriters, and to the general public.

However, these parties differ in the nature and degree of their concerns. For example, the concern of regulatory authorities is constrained by their statutory mandates, their operating budgets, and their need to focus on specific high-priority areas. Both owners and workers are concerned about workplace injuries, but because owners do not feel the same financial and psychological costs of injuries as the workers do, owners may logically be somewhat less concerned about preventing injuries than workers are. (This is not to suggest that owners and operators are not concerned about worker safety, but only that their concerns differ in intensity from those of the workers and their families.) Similarly, environmentalists and commercial and sports fishermen may be more concerned about environmental damage due to chronic oil spills than are workers and operators, while workers may be relatively more concerned with general rig maintenance problems than are environmentalists or fishermen. These differences in the foci of concern for different types of offshore hazards and in the relative magnitudes of those concerns will be shown later to have important implications for the appropriate use of risk analysis in risk management.

1.3.2 Magnitude and Frequency Characteristics of Offshore Risks

It is useful to classify offshore loss events into those that are chronic, recurring, and individually small in size, from those that are infrequent and have catastrophic consequences. (Logically, this classification scheme should also include small, infrequent loss events as well as large, frequent ones. Ordinarily, however, no one is concerned with managing the former, while no industrial activity that has the latter characteristics is likely to remain in favor with anyone!)

The class of small, chronic and recurring loss events is typified by routine worker injuries due to slips and falls, the dropping of heavy items from high places, chronic releases of contaminated water to the surrounding ocean, and the slow corrosion and fatigue of structures from exposure to the elements.

The class of large, infrequent offshore loss events is typified by the loss of well control with subsequent fire or spillage of oil in large volumes, and the total loss of a platform due to structural failure, storm or earthquake with consequent multiple loss of life. Often, regulatory authorities give more attention to preventing large and infrequent events, even when the aggregate losses due to chronic events are the same or greater. This is not unreasonable, since, as discussed in chapter 2, the public expresses greater concern about single, large losses than about an equivalent sum of small ones. As shall be shown later in this report, in practice the use of formal methods of risk analysis has reinforced this tendency to emphasize large loss events.

1.4 THE CHANGED NATURE AND CONTEXT OF OFFSHORE ACTIVITIES SINCE 1973

During this project, it became clear that it would be useful to compare the current nature and context of offshore oil and gas development in the United States with the circumstances of the industry a decade ago; that is, in 1973. The reason for taking this perspective is that the current framework for offshore oil and gas regulation is based in part on analyses of the circumstances that prevailed at that time. (Marine Board, 1972; Kash, et al., 1973) Furthermore, the international oil economy has undergone a series of revolutionary changes since 1973. A number of observations about these and other changes will help set the stage for this study.

First, until the oil embargo of late 1973, the American public and their leaders were essentially unaware of the importance of imports to the supply of energy in this country. The few instances of fuel oil shortages that had been experienced in the preceding winter, and the occasional gasoline lines of the summer of 1973 were attributed by the public, the press, and political leaders to poor planning by the oil industry. The world price of oil at that time was approximately $2.50 per barrel, as compared with $29.00 in 1983, and retail prices of gasoline were on the order of $0.39 per gallon, as compared with three to four times as much in 1983. The idea of national energy self-sufficiency ("energy independence") had not yet emerged as a political response to the "Energy Crisis".

In 1973, nearly all offshore oil and gas operations in U.S. waters were located in the Gulf of Mexico and off the coast of Southern California. The only other offshore production was in state waters off southern Alaska. In 1983 offshore fields accounted for 14% of domestic oil production, as compared with 17% in 1973. While exploration had been underway in the North Sea for a number of years, only a few producing wells had been completed in that area of the world.

The offshore regulatory system in use today was codified by the 1978 Outer-Continental Shelf Lands Act Amendments. This legislation has some of its origins in a major study of offshore energy management that appeared in 1973 under the title, <u>Energy Under the Oceans</u>. That study, financed by a grant to the University of Oklahoma from the National Science Foundation, was authored by D.E. Kash, I.L. White, and others. (Kash later served during the Carter Administration as the Associate Director of the U.S. Geological Survey for the Conservation Division, which became the Minerals Management Service in 1982.) Another influential analysis of offshore technology and regulation was published by the Marine Board in December 1972 under the title, <u>Outer Continental Shelf Resource Development Safety</u>.

<u>Energy Under the Oceans</u> reveals that in 1973 the principal offshore hazard of concern to environmentalists was damage to waterfowl. This concern was no doubt due to the widely publicized waterfowl losses that followed several major tanker accidents of the early 1970's. Similarly, the Marine Board study was concerned only with environmental pollution and did not address personnel safety at all. By contrast, the same interests are now primarily concerned

about the effects of toxic discharges on the productivity of benthic organisms, and there is greater awareness of the threats to workers from injuries and exposures to hazardous chemicals in the offshore industry.

In 1973 and 1974, the first attempts to apply probabilistic risk analysis to offshore risks were published. Two contracts were awarded by the USGS, then the regulatory agency for offshore energy, to consulting firms to assess the potential utility of these methods in offshore risk management. (Franz, et al., 1973; General Electric Co., 1974.) These contracts were let in response to an earlier NASA-performed study which suggested that probabilistic risk analysis, which had been used successfully in NASA projects, might be useful in offshore risk management. (Dyer, et al., 1971) (For further details on the two projects, see chapter 4 of this report.)

In 1973, firms operating offshore in the U.S. were at the forefront of the state-of-the-art in offshore technology, and they had amassed the bulk of offshore operating experience world-wide in any environment. The producing nations with regulatory systems and concerns similar to those of the U.S., namely the U.K. and Norway, had only begun to amass experiences that might be usefully transferred to the U.S. context. This should be contrasted to the situation now, when those nations and their operators haveconsiderably more experience in operating and regulating under hostile field conditions than do U.S. operators and regulators.

Another major change from 1973 to the present day is the explosive growth in the use of formal methods of analysis in regulatory decision-making in the U.S. In 1973, the only requirement for formal analysis was the National Environmental Policy Act of 1969 which mandated the performance of Environmental Impact Statements for any major Federal action having an adverse environmental impact. Some environmental laws required that decisions under them be based on the results of analyses of risk or of costs and benefits, but they had little impact on the offshore regime. Furthermore, many of the applicable environmental laws were passed between 1970 and 1972 (e.g., Clean Air Act and Occupational Safety and Health Act in 1970, Federal Water Pollution Control Act Amendments and Coastal Zone Management Act in 1972), and by 1973 they had not yet reached the stage at which their implementation had put clear burdens on the regulatory system. By contrast, in 1983, agencies, unless forbidden by law, are required by Presidential Executive Order 12291 to base their major regulatory decisions on an explicit cost/benefit analysis. Furthermore, court decsions have increased the burden on agencies to show that their regulatory decisions are based on the results of careful analyses. (See chapter 5 for more details on requirements for regulatory and safety analysis.)

The overall tenor of business-government relationships has changed dramatically over the decade, 1973 to 1983. In 1973, government appeared to be at great odds with business. New regulatory regimes were introduced on a regular basis, with little explicit attention to the costs they might impose on business operations. The oil industry was widely thought to be omnipotent, and was viewed with great mistrust by many in government.

Nothing could have changed more during the last decade than the prevailing attitude of government officials toward business. Today, politicians of all persuasions compete to do more to help revitalize American industry, including varieties of regulatory reform. Regulatory relief is a major element of the Reagan Administration's economic recovery plan. Similarly, it would appear that government is not viewed by industry as an antagonist, and industry representatives have been more willing to cooperate with government regulatory agencies.

Finally, the last decade's extensive reorganization of the natural resource management agencies of the Federal government can not be overlooked as a major change in the context of offshore activity. Foremost is the formation in 1977 of the Department of Energy, which raised energy-related issues to Cabinet level. In 1982, the Conservation Division of the USGS, the part of that traditionally scientific agency charged with regulating offshore energy, became the basis for the formation of the Minerals Management Service. This signaled that controlling offshore resources and their associated risks was no longer seen as a technical issue, and that their management had become an important area of public policy concern. Finally, during the last decade, several interagency memoranda of understanding have been promulgated to manage problems of overlap and conflict among the requirements of the Federal agencies with jurisdiction over offshore safety and environmental protection.

All of these changes during the last decade have important implications for whether the current regulatory framework and the methods it uses for managing offshore risks are adequate for the anticipated development of hostile offshore regions where new and untried technologies will often be used. The remainder of this report examines this important question.

1.5 RATIONALES FOR OFFSHORE SAFETY REGULATION AND R&D SUPPORT

In analyzing public policies for offshore risk management, it is useful to examine the rationales that underlie the government's roles in regulating offshore safety and environmental risks and in supporting research and development to improve offshore technologies. The issue of whether such government activities are appropriate has been frequently raised in the United States, and it has been reemphasized during the current administration. The basic question is whether the private sector can adequately address these needs, or whether government must supplement private activities in order to enhance the performance of the market and to protect interests that the market may otherwise underemphasize.

The most straightforward rationale for offshore safety and environmental regulation is that offshore development takes place on lands that are owned in common by the people of the United States, and that operators are there to exploit offshore resources only at the sufferance of the people acting through their government. Unlike most industrial activity whose fundamental purpose is to serve private interests, offshore operations take place for the benefit of the nation as a whole. Thus, the nation is free to impose requirements of its choosing on those private parties that find it profitable to recover the common resource.

At the same time, of course, once the decision is made to exploit the common resources of the ocean using private operators, it is necessary that the private operators be allowed to earn a reasonable return from their investments and efforts. Otherwise, private operators will not come forth and the public will not enjoy the fruits of its resources. Thus, regulatory controls on operators must be reasonably consistent with both private interests and the public interest.

The second rationale for regulation is that, in the absence of regulation by governmental authorities, there are insufficient incentives to keep offshore operators from damaging the natural environment and other aspects of the productivity of the ocean. This results from the classic failure of the market to put prices on those resources. Operators also have less incentive to correct situations that can lead to worker injuries and deaths than workers, their dependents, or the public might prefer. This results from the unsymmetric access to both information and control systems that workers and operators have, from the ability of operators to spread their risks through insurance and the scale of their activities, and from the existence of certain practices such as state workmen's compensation laws that limit a firm's liability to pay for the full costs of accidents.

On the other hand, since operators do have to pay for the costs of offshore accidents associated with losses of property or of the energy resource itself, they are concerned to make offshore activities safe. The fact remains, however, that because the incentive structures are different, the different parties find different levels of risk to be acceptable. In a competitive world, even well-intentioned operators can not afford to reduce these risks to a level that workers, environmentalists, and the public would find acceptable, unless their less-scrupulous competitors are required by law to do the same.

Similar considerations underlie the government's role in supporting research and development on offshore technology, especially that which relates to safety and environmental control. As a rule, industry tends systematically to underinvest in developing improved technologies, and this tendency is greater for process technologies, which are the dominant type used offshore. This fact, which can be demonstrated both empirically and using a theoretical economic analysis, has been used to rationalize a government role in supporting R&D in a number of areas, in addition to offshore technology. Furthermore, it is often argued that government has an obligation to help develop the new technology needed to cope with its own regulatory requirements, and that it can help to stimulate discovery and more rapid implementation of such new technology by industry if it does its own reearch on the subject. (The argument is that there is a disincentive for industry to develop better ways of controlling safety and environmental hazards, since to do so is to invite more stringent regulation.) Finally, it can be argued that government officials need to have their own connections with the R&D community in the areas in which they regulate to enhance their capabilities to regulate efficiently and fairly. Unless they have intimate knowledge of new developments in offshore technology, regulators may make serious errors in promulgating and updating regulatory requirements. Supporting R&D can provide a window on technology that government officials can not otherwise open.

These arguments do not exhaust the rationales that have been offered for offshore safety regulation or for support of R&D on offshore technology. However, they suffice to give a sense that such programs and activities need not be thought of as unwarranted intrusions into the prerogatives of private firms and operators, but as constructive contributions to maintaining a viable offshore industry. The challenge for regulatory authorities is to limit that intrusion to the minimum necessary and to use regulatory approaches that give operators the maximum flexibility in achieving broader public goals. Formal risk analysis may offer another opportunity for government and industry to work together toward their individual and shared goals.

1.6 ORGANIZATION OF THIS REPORT

Chapter 2 of this report provides an intoduction to concepts, issues and methodologies used in risk analysis of engineered systems. Particular attention is paid to the definitions of key terms, in view of the variety of definitions that are used in both the professional and lay literature on. Common methodologies are described and illustrated, and the strengths and limitations of the most widely used ones are discussed. The reader who already is conversant with risk analysis methods is encouraged to read at least the first part of chapter 2 to ensure that he understands which definitions we are using.

Chapter 3 describes and analyzes in some detail the offshore regulatory systems of the United Kingdom and Norway. It is based on a field study of the two countries by project staff, and on extensive documentation of their practices. (Details of the field study are given in chapter 3 and in the appendix.) Special attention is given to the use of risk analysis in the two countries and to the role of their governments in supporting research and development on safer offshore technologies.

Chapter 4 reviews experiences with formal probabilistic risk analysis in the U.S., the U.K. and Norway as applied to offshore problems. It also reviews major studies of risk management in the three countries in order to give a better understanding of the issues in each country and to show the degree to which formal analytical methods are used in each in addressing important policy problems.

Chapter 5 draws upon the experiences of the other countries and of the U.S. in both offshore and other kinds of regulation to show how risk analysis might be more widely applied to the offshore regime in this country. The chapter discusses trends in both public regulation and doctrines of private liability as a backdrop against which to understand the growing importance of formal analysis in managing safety and environmental risks. It also shows how the performance of each of the major functions of the Minerals Management Service might be enhanced by taking advantage of the capabilities of risk analysis.

Chapter 6 integrates the project and summarizes the findings, observations and policy options identified in the earlier parts of the report. It notes where risk analysis may play a role, and also comments on its strengths and its limitations in managing offshore risks.

CHAPTER 2

DEFINITIONS, CONCEPTS, AND METHODS IN RISK ANALYSIS

2.1 INTRODUCTION

Since the early 1960s, there has been an explosion of interest in formal, systematic approaches to identifying, analyzing, and managing the uncertain and undesirable consequences associated with the use of modern technological systems. A qualitative change has occurred in how we think about controlling hazards and about managing safety in industry and government. Fundamentally, attention has shifted from add-on devices that seek to limit the damage from undesirable events, to procedures that are intended to anticipate accidents and to change the fundamental design of products and processes so as to reduce the likelihood and/or severity of accidental events.

Such fields as risk analysis, risk assessment, and reliability engineering have come of age during the last two decades as systematic methods for implementing the new philosophy of systems safety. These methods were originally developed for improving the reliability and safety of complex defense and space systems and were adopted for such civilian areas as nuclear power plants, airliners, and chemical plants. Similarly, structural reliability methods were developed as improvements over deterministic design methods to help account for the inevitable imperfections in materials and devices, for materials fatigue under cyclic loadings, and for the fact that the loads applied to structures are often randomly varying with time. The advent of powerful computers facilitated the complex calculations that these analytical methods usually involve.

During the same period, concern grew rapidly for the damage that modern technology can do to the natural environment, worker and consumer safety, and human health. The subsequent rapid growth in the 1960's and 70's of governmental regulation to control this damage embodied needs to set standards of control, to establish priorities for the attention of government officials and industry, and to fix appropriate objectives for the socially desirable levels of safety in circumstances where, by definition, the marketplace is incapable of doing so. Modern methods of risk analysis and risk assessment have proven to be powerful adjuncts to the judgments of public officials who must make these critical decisions.

Because the broad field of risk analysis has such diverse origins (as well as other origins not discussed here in such fields as financial analysis and the assessment of the risk of political change in foreign nations), a variety of definitions is used for some of the key terms and concepts. In addition, the methodologies implied by such terms as "hazard analysis" often differ.

In order to clarify the scope and intent of this study, this chapter sets out the definitions we are using for key terms, discusses a few central concepts in the field, and outlines some of the basic methodologies of risk analysis.

Risk analysis is a large field with a vast and growing literature and its own professional society, the Society for Risk Analysis. Two important journals are Risk Analysis, published by the Society, and Risk Abstracts. For further reading, one should see, for example, the books by Henley and Kumamoto (1981), Rowe (1977), Lowrance (1976), Lees (1980), Wilson and Crouch (1982), Frankel (1984), and Roland and Moriarty (1983); along with reports by the Marine Board of the National Academy of Engineering (1972, 1981, 1984), SINTEF (Andersen, et al., 1983), Vinnem (1982), and the "Ramusssen" report on nuclear reactor safety (Nuclear Regulatory Commission, 1975). Some of the material in this chapter is adapted from a thesis and report by Cheney (1983) that was written for this project.

2.2 DEFINITIONS OF TERMS

2.2.1 Risk

The word "risk" is used in at least two ways in the risk analysis literature. "A risk of" tends to be synonymous with the word "hazard", and refers to any uncertain and undesirable event or to the outcome of such an event. For example, one speaks of "the risk of" an explosion in a dynamite factory or "the risk of" health effects from exposure to a hazardous chemical. This is the more intuitive use the word risk which corresponds roughly to the dictionary definition of risk as "a possibility of loss or injury". It gives rise to the notion that risk analysis includes any sort of careful study of undesirable events and consequences, and to the colloquial use of "a risk" to mean any undesirable event or outcome. In the latter sense, risk is roughly synonymous with hazard and loss.

A more precise definition of "risk" used by some practitioners of formal risk analysis is that risk is "a compound measure of probability and magnitude of adverse harm" (Lowrance, 1980). This measure, which has meaning only over a specific period of time, can be expressed mathematically as shown by the following (Henley and Kumamoto, 1981):

$$\underset{\left(\frac{\text{consequences}}{\text{unit of time}}\right)}{\text{RISK}} = \underset{\left(\frac{\text{events}}{\text{unit of time}}\right)}{\text{FREQUENCY}} \times \underset{\left(\frac{\text{consequences}}{\text{event}}\right)}{\text{MAGNITUDE}}.$$

For example, the risk of death from car accidents in the U.S. can be approximated by:

$$50{,}000 \text{ deaths/year} = (50 \times 10^6 \text{ accidents/year}) \times (10^{-3} \text{ deaths/accident}).$$

For an activity with only one kind of risk, this definition corresponds to the statistical "expected value" of harm. More generally, for an activity that may cause several kinds of harm, the expected value of harm (i.e., the risk) is the sum, over each of the kinds of harm, of the probability of that kind of harm, given that the harmful activity occurs, multiplied by the magnitude of the consequences of that kind of harm. In this more rigorous perspective on risk, risk analysis is a process for identifying and describing the undesirable consequences of an activity and for showing the relationships among their causes, probabilities, and magnitudes.

Finally, even in the professional literature on risk analysis, it is not uncommon to see the word "risk" used to refer only to the probability that an undesirable event will occur in a given time. For example, one will see expressions such as, "The risk of injury from using this tool is one in 10,000," when what is meant is that the probability of injury is one in 10,000. Such usage no doubt arises from the fact that the magnitude of the harm is assumed to be adequately understood in such cases and that the probability statement is sufficient to capture the concern for loss. However, when the harm is complex (for example, several sorts of losses are involved or the expected value of harm per unit of time is a combination of harms of several independent outcomes having different patterns of occurence), then it is insufficient to use the word risk to refer only to probability.

2.2.2 Hazard, Safety, and Reliability

Three other words are of importance here. "Hazard" is defined by Webster's as "a source of danger". Thus, it is appropriate to speak of the "risk of a hazard", as in the risk of skiing or the risk of living near a munitions plant, where the source of danger; i.e., the hazard, is the act of skiing or the presence of the plant.

"Safety" is defined by Webster's as "the condition of being safe from undergoing or causing hurt, injury, or loss." Unfortunately, this definition connotes absolute freedom from such events, whereas it is only useful to think in terms of relative safety, which is a condition of being relatively safe, or acceptably safe, from undergoing or causing hurt, injury, or harm.

"Reliability" means "the quality or state of being suitable or fit to be relied on." Typically, reliability and reliability analysis focus on the probability that a system <u>will perform</u> as it is intended to, whereas risk and risk analysis focus on the probability as well as the consequences of a system <u>failing to perform</u> as intended.

2.3 ISSUES IN RISK MANAGEMENT

2.3.1 Risk Perception

Individuals' beliefs about, or perceptions of the magnitudes, probabilities, expected values and relative rankings of risks generally differ from their objective values as determined by scientific measurements and models of these attributes of risk. (Slovic, et al., 1980) For example, many people believe that airplane travel is more risky than automobile travel, although, based on historical records, the probability of death per passenger mile from riding in commercial airplanes is lower.

A large and growing literature is focused on why lay people perceive risk differently from experts. Fischhoff, et al. (1981) suggest that people's experiences and anxieties, along with differences in the media coverage of risks, contribute to the discrepancy between the "perceived risk" and the computed risk based on historical records. Another explanation for the difference is that most people have little feeling for small probabilities. The difference between a probability of death of 10^{-4}/year and 10^{-6}/year cannot be grasped by most people. Another view is that people do not naturally think in terms of probability and consequences at the same time -- they focus on either the consequence of an event or its probability, but not on both at once. For example, some people focus on the large potential consequences of a nuclear reactor accident, while others focus on the low probability that such an accident might occur, but few focus on the calculated risk, which is the product of the two. Furthermore, where one focuses in such cases is determined not only by the objective evidence but also by one's beliefs and preferences about how the world does or should work.

2.3.2 Acceptable Risk

The concept of <u>acceptable risk</u> refers to how individuals, groups and society determine which risks are acceptable. (Fischoff, et al., 1981) The acceptabilities of the risks of a set of hazards usually do not correspond to their expected values of harm. Researchers have identified many factors, other than a straightforward calculation of the probability times the consequence, that influence the acceptability of a particular risk. Among these are the magnitude of the consequence itself, the benefits of the risky activity, the extent to which the risk is borne voluntarily or imposed on one by others, and the newness of the risk. Usually, society considers rare, high-magnitude risks to be less acceptable than frequent, low-magnitude risks, even when both have the same expected value.

Researchers have found that people accept voluntary risks, such as those due to mountain climbing or motorcycling, that are a hundred or more times greater than the involuntary risks that they find unacceptable. (Starr, 1969) In addition, the degree to which people understand a risk influences its acceptability, and this is reflected in the historical shift in society's expectations for the control of particular risks as more has been learned about them. Finally, groups may find risks to be more or less acceptable as a function of the social setting, as reflected in the greater propensity of large groups, than of individuals, to take risky actions.

2.3.3 Public Decisionmaking Implications of Risk Perception and Acceptability

The concepts of risk perception and risk acceptability play important roles in the political processes of decisionmaking about the control of risks. Basing policies on the objective probabilities and consequences of a risk may lead to the most economically efficient policies, but basing policies on how a risk is perceived by the public may lead to policies that are more widely accepted as correct. The regulatory agency administrator who must choose among a variety of risks to control, and among a variety of levels and types of control, is confronted with a difficult problem. The administrator has the choice of making a decision based on the expected value of the risk, which may not correspond to public preference, or of making a decision based on public opinion, which is often divided, misinformed, and volatile. Furthermore, a public official can seek either to reduce the risks that have the greatest expected value, or to reduce the risks that are the least acceptable. These alternatives actions are not usually the same, and research suggests that different risks would receive different priorities under each goal. (Starr, 1969)

The degree to which a risk is borne voluntarily or involuntarily affects public expectations and preferences for its control. People often object to governmental controls on risks that they have chosen to face, such as hazardous sports or fast driving, while they strongly support governmental programs to control the risks that other people impose on them, such as workplace hazards or unsafe consumer products, even if the latter, involuntary risks are smaller.

2.4 DEFINITIONS OF RISK ANALYSIS AND RELATED CONCEPTS

The literature on risk uses concepts that sound quite similar, such as "risk analysis" and "risk assessment". Unfortunately, clear distinctions are rarely drawn among them, and different authors give the same terms and phrases different, though similar meanings. Up to now, no consensus has emerged on the exact definitions of the various terms. Since these phrases and terms are used to delineate what the writer intends to include or exclude from a given discussion, or policy, with respect to risk, it is important to pay attention to how they are used.

2.4.1 Risk Analysis

Risk analysis can be defined as the process of identification and qualitative or quantitative description and analysis of risks. This report is concerned primarily with risk analyses of engineered systems, as opposed to financial risk analysis (such as an investment banker might use), political risk analysis (such as a student of foreign affairs might use), or health risk analysis (such as a toxicologist might use to estimate cancer rates from exposure to chemicals). The latter types of risk analysis use different methodologies and pose different issues from the ones considered in the present study. As we use it, risk analysis includes all of the steps in analyzing risks, up to and including the analysis of the consequences of an undesirable event. However, it does not include the assignment of value to those consequences in dollar or in other terms (a process we refer to as risk evaluation), nor does it include the design or operation of systems to control risks.

2.4.2 Risk Assessment

Risk assessment can be defined as the analogue of risk analysis for cases in which the risk in question endangers human health or the environment as the result of exposure to a chemical hazard. While there is little conceptual difference between risk analysis and risk assessment as we use them, it should be noted that some authors, especially those who write about the risks of engineered systems, use the term "risk assessment" to refer to the process of risk evaluation, described above. We do not use the words this way. Still other authors define risk assessment as putting a risk in context by comparing it with other risks or societal norms. In effect, they are using risk assessment as shorthand for what is sometimes called "comparative risk assessment."

The methodologies used for risk analysis of engineered systems and risk assessment of chemical hazards differ greatly. In particular, in a risk analysis of an engineered system one is concerned with accident events whose occurence is highly uncertain, but whose consequences, if the event does occur, are highly predictable; whereas in a risk assessment of a chemical hazard one is concerned with exposures whose occurence is highly predictable, but whose consequences for any individual, if exposure occurs, are highly uncertain. An example of the first type of accident event is the highly uncertain possibility that a rig will experience a wellhead fire, with reasonably certain injuries to workers if a fire occurs. An example of the second type of hazard is the certainty that a worker in a factory making carcinogens will be exposed to carcinogenic chemicals, with a high uncertainty about whether his exposure will lead to cancer in later life.

2.4.3 Reliability Analysis

Reliability analysis refers to studies of the failures of an engineered system which do not usually consider the consequences of such failures. For example, estimating the probability of failure of an offshore structure or of an offshore processing system would be a reliability analysis; but adding a determination of the economic, environmental, and human consequences of such events would make such studies risk analyses. (Henley and Kumamoto, 1981) Furthermore, reliability analysis typically focuses on the probability of successful operation, viewing failure as an exceptional case, while risk analysis typically is concerned with unsuccessful operation. In practice, risk and reliability analyses are often indistinguishable.

2.4.4 Structural Reliability Analysis

Structural reliability analysis is a class of reliability analysis that focuses on the integrity of structures subject to variable loadings, made of elements having uncertain mechanical properties, and whose behavior is described by undertain models that include simplifying assumptions and unknown boundary conditions. With this approach, some risk of unacceptable structural performance is tolerated. The goal of structural design based on reliability analysis is to ensure, at an acceptable level of probability, that the structure will not become unfit for its intended purpose at any time during its specified design life. Structural reliability analysis is concerned with multiply-connected mechanical systems for which the response is treated as a continuous function of load, at least up to a strength limit, whereas risk analysis is concerned with systems whose components are usually treated as being in only one of two states: functioning properly or failing.

2.4.5 Risk Management

Risk management is defined as the entire social process of controlling risks. It includes risk identification, risk analysis, risk assessment, risk evaluation, and the design and execution of programs, procedures and systems to control risks in order to acheive some target of acceptable risk. In the private arena, risk management includes all of the activities of safety engineering, as well as the operational aspects of ensuring safe conduct of activites. In the public sector, risk management includes promulgating and enforcing regulations for safety, whether those regulations take the form of standards of conduct, monetary incentives and disincentives, the provision of risk information, or the modification of the rules of private liability actions.

Some authorities, such as the National Research Council Committee on the Institutional Means for Assessment of Risks to Public Health, which recently produced a report on risk assessment in the regulatory process (National Research Council, 1982), define risk management in a more narrow sense. They reserve "risk management" to refer to the decisions and actions taken to control risks, and they exclude the risk identification, analysis, and evaluation steps from the risk management function. Strategically, however, this makes little sense since risk managers must somehow decide which risks to control and in what order to control them, as well as how to control them. This means that risk identification, analysis and assessment must be part of the risk management process, and the division of the overall risk problem into two categories, risk assessment and risk manaagement, is logically untenable.

2.4.6 Risk/benefit Analysis

Risk/benefit analysis combines risk analysis and cost-benefit analysis by comparing the costs of imposing controls to reduce risks with the benefits of that reduction. Both are measured in common units such as dollars.

In a variant of this meaning, some writers define "risk/benefit analysis" as the process of comparing all the risks of using a technology with all the benefits of such use, in the sense, for example, that one might compare the benefits of recovering offshore oil against the risks that offshore activity might cause illness or death in order to determine whether to proceed with offshore resource development. It is unusual, however, to face a "Go/No-Go" decision either to (i) accept all of the risks and all of the benefits of a technology, or (ii) forego both the risks and the benefits entirely. More frequently, one faces a decision on the margin about whether some portion of a technology's benefits might be given up in order that some increment in safety might be gained. Thus, this second formulation of risk/benefit analysis is actually only meaningful in unusual circumstances.

2.4.7 Safety Systems

Safety systems are systems of hardware, software and organizations that are added to an engineered system to help forestall the occurence of accident events having undesirable consequences or to help manage the undesirable consequences of an accident event if it does occur. For example, a pressure relief valve, a vent line, and a vent flare installed on a pressure vessel that contains flammable hydrocarbons would be a safety system, as would a sensor and a valve to shut down a heating unit under such a vessel in the event that its pressure rises dangerously high. Similarly, fire fighting equipment and fire fighting procedures on board an offshore rig constitute a safety system.

2.4.8 Systems Safety

By contrast to safety systems, "systems safety" refers to an approach to the design and evaluation of engineered systems that is based on systematic, forward-looking identification and control of hazards throughout the system's life cycle. (Roland and Moriarty, 1983) It emphasizes the interactions of failures in any part of the system with the performance of all of the other components of the system. Thus, while a systems safety study might be concerned in part with the adequacy of safety systems, safety systems may not necessarily be designed from a systems safety point of view. Substantial confusion can arise from the incorrect ordering of these two words. In particular, the fact that a project is equipped with safety systems does not necessarily mean that it has been designed, built and operated from a systems safety point of view.

2.5 METHODS FOR ANALYZING THE RISKS OF TECHNICAL SYSTEMS

The many risk analysis methods vary in their degrees of formality, in the way the analysis is structured, and in how and by whom they are commonly used. This section defines, describes, and assesses these methods, compares and contrasts their strengths and weaknesses, and describes their appropriate uses. This section provides only a brief overview of the essential characteristics of the most popular methods of risk analysis used for offshore systems. For details on these and other methods, the reader is referred to the books listed at the beginning of this chapter. The risk analysis methods summarized in this chapter can be placed in one of four general categories:

<u>Logic diagram methods</u>, which graphically depict the relationships between the failures of components and failures of a system. These methods include fault trees, event trees, cause-consequence diagrams, success trees, and reliability block diagrams.

<u>Matrix methods</u>, which use matrices, charts and check lists to structure information about the ways a system can fail. These methods include preliminary hazard analysis, failure modes and effects analysis (FMEA), and hazard and operability studies (HAZOPS).

<u>Structural reliability analysis</u>, which connects the long-term response of a complex and imperfect structure to variable environmental and other stresses.

<u>Judgmental analyses</u>, which emphasize human and social factors, and include safety studies by expert committees.

<u>Consequence modeling</u>, which is a large family of models of the effects on surrounding structures, equipment, environments, and personnel of such phenomena as fires, explosions, releases of plumes of gases or liquids, and mechanical and electrical releases of energy and mass.

2.5.1 <u>Logic Diagram Methods</u>

Fault trees, success trees, event trees, cause-consequence diagrams, and reliability block diagrams each graphically illustrate the logical relations between the failures or successes of components and the failure or success of a whole system. The methods differ in the types of diagrams used to display the relevant relationships, in whether they analyze the consequences or the causes of an event, and whether they show the relationships that cause a system to work or to fail.

<u>Fault trees</u> are logic diagrams that show the combinations of basic events, such as component failures, that can lead to a "top event", such as a system failure or undesired hazard. (See Figure 2.1)[1] The analyst begins with the

[1] All of the figures for this chapter appear at the end of the chapter.

top event and creates a tree by asking "what event or combination of events could lead to this event?" When either event A or event D could lead to failure of subsystems 1 or 4 respectively and thus to system failure, the basic events, A and D, are connected with an "or" gate. When both B and C must occur in order for subsystem 2 to fail, they are connected with an "and" gate. While these are the two basic types of gates, other gates are sometimes used to show more complex relationships among events. The qualitative result of a fault tree is a list of "cut sets", which are the combinations of basic events that can lead to the top event.

Fault trees are used to describe how failures have occurred or might occur; they can also be used to make quantitative estimates of failure probabilities. The probability of the top event occuring can be derived using Boolean algebra from the probabilities that each of the basic events will occur and from the logical relationships among the basic events and the top events. For example, if the system fails only when B and C fail, and if B and C each fail independently with a probability of 0.1 per year, then the probability of system failure is 0.1 x 0.1 = 0.01/year. Fault trees are most helpful in estimating the probability of a system failure from estimates of the failure rates of the individual components of the system.

In contrast to fault trees, which begin with a top event and search for its causes, an event tree starts with an "initiating" event, such as a component failure or an improper operational procedure, and shows the consequences of that event for the other components and for the system as a whole, contingent on other ensuing events. For example, in Figure 2.2, the consequences of a gas leak depend on whether the gas is ignited and on whether the fire fighting system works. As with fault trees, event trees can be used to describe how consequences can occur or to predict the risks from an as-yet unquantified hazard. Event trees can also be used to quantify the probability of an undesirable consequence from the probabilities of the initiating and ensuing events. In the example, one could estimate the probabilities of large, moderate, and small damages from estimates of the independent probabilities of a gas leak, availability of an ignition source, and failure of a safety system. The probabilities of the initiating and ensuing events can be estimated from historical records, from expert judgment, or from models including fault trees. For example, the Reactor Safety Study (WASH-1400 or the "Rasmussen" report, an early major risk analysis of a nuclear power plant) (Nuclear Regulatory Commission, 1975), used fault trees to estimate the probabilities of the branches of an event tree.

When fault trees and event trees are combined in one diagram, the result is a cause-consequence diagram. In a cause-consequence diagram, the causes of events are described by fault-trees and the consequences of the same events are described by event-trees, as shown in Figure 2.3. Cause-consequence diagrams are very flexible.

Unlike the previous methods, which analyze how systems fail, success trees show how systems perform properly. Success trees are thus the mathematical "dual" of fault trees. One can convert a fault tree into a success tree by defining all the "events" as successes instead of failures, changing all "and" gates to "or" gates and vice versa, and changing all failure probabilities, P, to success probabilities, (1-P). Success trees identify the components that need to work for the system to work.

Reliability block diagrams show the same information as success trees, but have a form similar to schematic diagrams, as shown in Figure 2.4. Events drawn in series are equivalent to the "and" gates of a success-tree, and events drawn in parallel are equivalent to "or" gates. The advantages of reliability block diagrams are that they show how a system works more directly than a success tree and that they are easier to follow. They thus make it easier for an engineer to tell what systems must work if the system is to work.

Logic diagram methods are the most promising, but also perhaps the most controversial of the risk analysis methods. They can be used to predict the level of safety of very complex systems from data about the components, and they focus the analysis on the most critical parts of a system. They offer greater promise than less formal methods of capturing "all" of the important risks in a complex system.

However, logic diagram methods have several strengths and weaknesses. They work best for systems composed of discrete components which fail independently of each other, in which each component either fails or does not fail, and in which components do not continue to perform when partially damaged. (Note that this latter characteristic makes logic diagram-based methods quite different from structural reliability analysis methods, which are designed to cope with imperfectly-performing elements.) Logic diagrams are appropriate for analyzing the failure of a system composed of discrete parts such as an oil refinery or an offshore processing facility, where one wants to know which combination of failures will cause which consequences. However, they are less appropriate for assessing the probability of failure of a system such as an offshore platform's structure, which has a high degree of interdependence between components. In the latter case, a fault-tree analysis might reveal that a platform could fail because of high winds, high waves, high currents, high seismic forces, or ship collisions, but this information is not very useful; one needs to know how quantitative levels of the various loadings will cause the structure to fail, rather than only what combinations of factors might cause failure. Logic diagrams provide little insight into such questions.

One can not be certain that a logic diagram includes all of the possible failure modes, or all of the important consequences of the failure of a system. Early risk analyses frequently overlooked important failure modes, such as human error or improper maintenance, that are now more commonly included. Thus, risk analyses of a particular technology can become more complete as experience identifies of failure modes omitted from an original risk analysis that can be included in future analyses. Lack of completeness does not make risk analyses useless, but it does reduce the validity of its prediction of the risks of using a new technology. Typically, omission of a failure mode biases the analysis in the direction of underestimating the true failure rate.

Conversely, correction of hazards during operations can cause the actual failure rate to lie below the predicted rate.

Quantifying the failure probabilities of a system from the failure rates of its components requires historical data on prior failures. This information may be obtained from data banks, reliability handbooks, engineering models (such as those that predict failure rates for offshore structures or assess the likelihood of a ship colliding with a platform), or expert judgment. Information from each data source will be uncertain: there is limited data on the failure of components, models are imprecise, and expert judgment is used only when the other sources are inadequate. The uncertainty in each datum leads to uncertainty in the calculated probability of each subsequent event, and in many analyses the uncertainty in the results can be a factor of ten. (Tveit, 1980; Nuclear Regulatory Commission, 1975)

Some causes of failure, such as sabotage, war, and human error, cannot be accurately quantified. For example, the National Aeronautics and Space Administration, a developer and extensive user of risk analysis does more qualitative than quantitative risk analyses because of the difficulty in quantifying human error.[2] (McInnis, 1982)

Detailed logic diagrams can be large, complex, abstruse and hard to follow. Some diagrams spread over many pages. Large, complex ones are often constructed with the help of a computer, and a computer is needed to calculate the top event probabilities. This complexity makes the analysis difficult for a lay person to comprehend, and makes it difficult for both analysts and interested parties to review analyses for accuracy.

Logic diagrams may not provide all of the information that is needed to do a complete safety analysis. Logic diagrams are good for describing how failures occur, but provide little insight into why failures occur or what can be done to prevent them. For example, a logic diagram can show how equipment failures and human errors cause blowouts, but would not show how boredom or lack of motivation contribute to the human errors. Furthermore, logic diagrams are often constructed by professional risk analysts rather than by people who have first-hand experience with the systems being analyzed. When the insights of people with the most relevant experience are ignored, analyses often omit relevant failure modes, especially those that can not be quantified.

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[2] NASA's risk analysis practices came under intense scrutiny following the explosion of the Space Shuttle Challenger in January 1986. These experiences were not considered in writing this report.

In summary, logic diagram approaches are powerful methods for describing and quantifying how systems fail, but they are limited. Their limitations do not prevent logic diagrams from being useful, but prevent them from being perfect. Logic diagrams can only produce estimates of risk, and these are based on imperfect and uncertain assumptions. Because these methods are uncertain, complex, difficult to decipher and filled with hidden assumptions, they are prone to misuse. When they are being used to convince rather than to assess, they can easily be distorted.

2.5.2 Matrix Methods

Matrix methods include preliminary hazard analysis, failure modes and effects analysis (FMEA), and hazard and operability studies (HAZOP). Each of these methods is a structured approach to thinking about the ways in which a system might fail, and each uses a matrix, chart or check list to guide the analysis. The different types of matrix methods are not precisely defined, and different analysts use slightly different procedures (Henley and Kumamoto, 1981). The techniques differ in the starting points of their analyses: a hazard analysis focuses on hazards, a FMEA focuses on the failure modes of equipment, and a HAZOP focuses on deviations from normal operations.

A preliminary hazard analysis is a formal procedure to identify (a) hazards (conditions that can potentially lead to injury, death, or environmental or property damage), (b) events that can transform hazards into accidents, (c) the consequences of accidents, and (d) measures to prevent accidents. The studies are usually done at a general level for a project as a whole, and they are often used as the first step of a detailed risk analysis in order to identify areas that need further study. Their advantages are that they are relatively quick and easy to do, and therefore inexpensive, and that they focus the analysis on the most important areas for further detailed investigation.

Failure Modes and Effects Analysis (FMEA) is similar to a preliminary hazard analysis, except that the starting points of an FMEA are the individual pieces of equipment rather than the individual hazards. (Figure 2.5 is an example of an FMEA format.) In doing an FMEA, the analyst goes through a system, component by component, considering each way each component can fail (its failure modes), the consequences of each failure, and the changes in the system needed to correct the failures. A related type of formal analysis is criticality analysis, an extension of FMEA which ranks failure modes on the basis of how critical they are to the operation of the system.

As a result of the fact that a detailed FMEA considers every failure mode of every component of a system, including those that are not directly related to safety, doing an FMEA can be time consuming. At the same time, however, it does not necessarily focus the analysis on the most important types of failure. By examining each component separately, this kind of analysis may miss failure modes arising from the interaction of system elements. Furthermore, FMEAs concentrate on equipment failures and tend to neglect human failures.

Hazard and Operability Studies (HAZOPS), like FMEA, are a class of systematic ways to think through a system to consider things that could go wrong with it. The starting point for a HAZOP is a systematic examination of the potential consequences of deviations from the normal conditions or procedures of a system. Unlike FMEAs, HAZOPs are not limited to equipment failures, but also include "operability factors" such as human errors.

HAZOPS are commonly performed by a team that includes a risk analyst, along with engineers or other knowledgable participants from design, construction, operations, maintenance, and management. The team uses a series of guide words to stimulate thinking about how conditions in the system could deviate from the normal. The team considers the possible causes of such deviations, their likely consequences, and actions that might be taken to prevent the deviation. For continuous-flow chemical plants or petroleum processing installations, typical guide words include no flow, high flow, low flow, reverse flow, high and low temperatures, and high and low pressures; each of which suggests abnormal conditions in the plant.

2.5.3 Structural Reliability Analysis

Until recently, structural engineering has been dominated by deterministic approaches characterized in design calculations by the use of specified minimum material properties, specified load intensities, and prescribed procedures for calculating stresses and displacements. For the most part, this approach to structural engineering has been embodied in design codes with little feedback about the actual performance of the structures. The use of design codes with relatively high factors of safety and the lack of information about actual behavior of the structures has led to the mistaken perception by many people, including both professionals and members of the general public, that absolute safety can be achieved. (Thoft-Christensen and Baker, 1982)

Structural reliability analysis, on the other hand, recognizes that for any but the most simple structures, there are uncertainties in the material properties comprising the structure, uncertainties in the loads applied to the structure and the environment, and uncertainties in the models used to describe the behavior of the structure. In this case, structural reliability is the probability that a structure will not reach limit states of failure or serviceability during a specified reference time period. (Thoft-Christensen and Baker, 1982)

The sources of uncertainty affecting the behavior of an offshore structure can be grouped in four main categories:

i. those affecting the loading
 - extreme wind speed
 - extreme current speed
 - the spectral form of the extreme sea-state
 - the extent of marine growth
 - hydrodynamic forces

permanent and semi-permanent deck loads
variable deck loads,

ii. those affecting the structural response
uncertain soil properties on natural frequency
variable deck loads on natural frequenecy
structural and hydrodynamic damping
peak response given a root mean square response,

iii. those affecting component strength
material properties
geometrical imperfections
model uncertainties, and

iv. those affecting systems behavior
ductility of materials
post-buckling strength of components.

Methods of structural reliability have been classified into a hierarchy of methods by the International Joint Committee on Structural Safety:

Level 1 - Design methods in which a number of partial safety factors related to nominal values of the major structural and loading variables are applied to structural elements or the entire structure,

Level 2 - Methods using approximate iterative calculation procedures to obtain an approximation of the failure probability of the structure, based on a simplified representation of the joint probability distribution of the variables; and

Level 3 - Methods in which the exact probability of failure of the structure or structural component is determined, using a full probabilistic description of the joint occurence of the quantitites affecting the response of the structure.

The widely-used recommended practice for planning, designing, and constructing fixed offshore platforms published by the American Petroleum Institute (American Petroleum Institute, 1982) is a strictly deterministic approach based on practices and principles which have evolved during the development of offshore activities in the U.S. More recently, guidelines have been investigated and proposed for modifiying the API recommended practice to included a Level-1 reliability-based design approach. (Moses, 1981) Level 2 methods, in addition to being used directly for structural design, can also be used in the design of Level 1 codes. (Thoft-Christensen and Baker, 1982; ASCE, 1983) Level 3 methods are currently beyond the scope of design for structures as complex as offshore platforms.

2.5.4 Judgmental Methods of Risk Analysis

For some purposes, structured approaches to risk analysis for offshore systems, such as logic diagrams and structural reliability analysis, are too expensive, time consuming or inconvenient. They can sometimes be replaced by judgmental approaches that are more qualitative and intuitive and that depend more explicitly on experts' judgments of overall effects, as opposed to data on component behaviors and interactions. Committees, workshops, and other methods of exploiting existing knowledge about risks use expert judgment and experience rather than analysis to assess risks. The Marine Board of the National Research Council in the U.S., and the Burgoyne Committee in the U.K. have used this approach to obtain a broad overview of offshore risks for public-policy purposes. (See chapters 3 and 4 for details of some of their studies.) At the other extreme, many operating companies use workers' safety meetings to identify and reduce operational risks on a day-to-day basis.

Informal and judgmental methods are most appropriate when there is direct experience with the risk, when there is no data and expert judgment must be relied on, or when the important issues at stake revolve around differences of values and preferences that cannot be resolved by analysis. In the latter type of circumstance, of course, the results of judgmental approaches depend very heavily on who participates in the analysis and what interests he is representing. Therefore, the selection of the participants in the analysis takes on added importance when the analysis is intended to inform the decisionmaking process, especially for governmental purposes.

Often a combination of analytic and judgmental approaches can be useful. In fact, most of the methods in use depend on a combination, and the difference between the two groups is more a matter of degree than of kind. Rarely, for example, can a fault-tree analysis be done without some expert inputs on the probabilities of component behavior, while on the other hand most expert panels make some use of quantitative methods in carrying out their work.

2.5.5 Consequence Analysis

It is one thing to use such approaches as matrix methods, logic diagrams, and structural reliability analyses to identify and estimate the probabilities of the occurence of undesirable events such as loss of well control, collapse of main platform supports, or fire in a process unit. It is quite another to model and to analyze the consequences of such events for the surrounding personnel, environment, and property. The analysis of accident consequences, which is not within the scope of the present report, can call upon many disciplines and perspectives. For example, models may be built to describe the consequences of fires, explosions, water-and air-borne plumes of gases or liquids, collisions of vessels with platforms, electrical malfunctions, and many others. Each of these draws upon a well-developed and highly specialized field of engineering analysis. In this project, we have not attempted to assess the state-of-the-art of these fields, nor have we reviewed the methodologies. Thus, we mention this aspect of the analysis problem here only for completeness and to remind the reader that, while it is sufficient for some purposes, for many others it is not enough to do the probabilistic analysis of events, and that consequences must also be examined.

For some purposes, of course, risk analysis must not only consider the consequences of undesirable events but must also attach values and costs to those undesirable consequences. This is required when risk analysis is used as an input to decision-making in which safety is being balanced against other valued outcomes such as the production of the resource, or the cost of achieving a safer system. Once again, a great deal of literature and expertise has been developed in attaching value to the undesirable impacts of human activities on the environment, safety and property loss. For a review of such methods and their limitations and problems, the reader is referred to such sources as Freeman (1979) and Ashford, Hill, et al. (1980).

2.6 CONCLUDING OBSERVATIONS

Because each method of risk analysis has both advantages and limitations, it is common for studies of offshore risk to use a combination of several techniques. An analysis often begins with a preliminary hazard analysis to identify hazards, followed by a fault-tree analysis to identify the causes of the hazards, and an event-tree analysis to quantify the consequences. Some studies have used hazard and operability studies to identify problem areas in the system, and have then used fault-tree analysis to quantify the risks. Others have used fault-tree analysis to describe the way a system fails, and have used the Delphi method to obtain estimates from experts on failure probabilities. Rather than viewing each risk analysis method as a complete tool, one should view them as an array of tools to be used as needed to accomplish a specific task.

The strengths and limitations of the various risk analysis methods and the characteristics of each application determine which method is most appropriate in each case. The important characteristics of the application are the purpose of the analysis, the type of risk, the nature and stage of development of the system, and the extent of the experience with similar systems and with risk analysis methods.

The common purposes of a risk analysis are to estimate unknown risks or to identify ways to reduce them. Estimating risks requires quantitative analyses using logic diagrams, structural reliability analyses, and other models, or extrapolation from the historical record. Determining ways to reduce risk does not require quantitative analysis, but does require insight into the system to identify ways to make it safer.

Offshore risks are of a variety of types. They vary according to the scale of the consequences, the type of consequence, the time period of the consequences, the frequency of the risk, and the cause of the risk. Offshore risks include risks to people, to the environment, and to property, and different kinds of analysis are appropriate for each. Assessing risks to the environment requires an understanding of the fates and effects of pollutants, and a risk analysis might require environmental consequence modeling that extends beyond the boundaries of the engineering system. Accidents that result in monetary damage are much more common than accidents that result in injuries or fatalities, and the extra data required affects the type of analysis that is most useful.

Different risk analysis methods are appropriate for addressing different causes of offshore risks. Some risks, including many workplace accidents and operational failures such as blowouts, are principally caused by human error, and methods of risk analysis that include the participation of people with direct experience are necessary to do useful analysis of such risks. Other risks are caused by environmental forces, such as waves, winds, and earthquakes, and require analyses of the effect of these forces on structures and operations. Still other risks arise from design errors, and logic diagrams are appropriate for detecting problems of this kind.

Analyses of large-consequence risks generally warrant a larger investment of time and money than small-consequence risks. Rare risks require a more analytic approach than higher-frequency risks, since there will be a larger base of experience for the latter than for the former.

Different systems require different methods. An offshore platform that might fail due to the cumulative force of wind and waves requires a different type of analysis than a production system that might fail because one of its components fails due to mechanical wear. A structural reliability analysis is appropriate for the former system, while logic diagrams are appropriate for the latter. Systems in which people have a major role must be analyzed using methods that take human behavior into account.

Another characteristic of a system that influences the selection of an appropriate method of analysis is the amount of experience with the system; that is, the extent to which the system is new and represents a major advance over previous systems. Technological systems that are simply evolutionary extensions of existing, tested systems do not require the same kind and degree of analysis that totally new systems should receive. For example, in the U.S. Gulf of Mexico, offshore production methods have evolved continuously from land-based technology, and there have been few discontinuities in technology development. Since each new system was only a minor advance over existing ones, its risks could be extrapolated from experience. Since the individual platforms were relatively small and inexpensive compared with some of the platforms now used in frontier areas, improvements in technologies could be based on experience; if a new technology worked it could be kept; if it didn't, it would be discarded. In the North Sea and in U.S. frontier areas, however, the technologies and systems face conditions that are quite different from the Gulf Coast, and they embody major discontinuities over previous technologies. Thus, prior experience cannot be relied on, and more elaborate analysis is needed both to determine the magnitudes of the risks of the new technologies and to correct their faults.

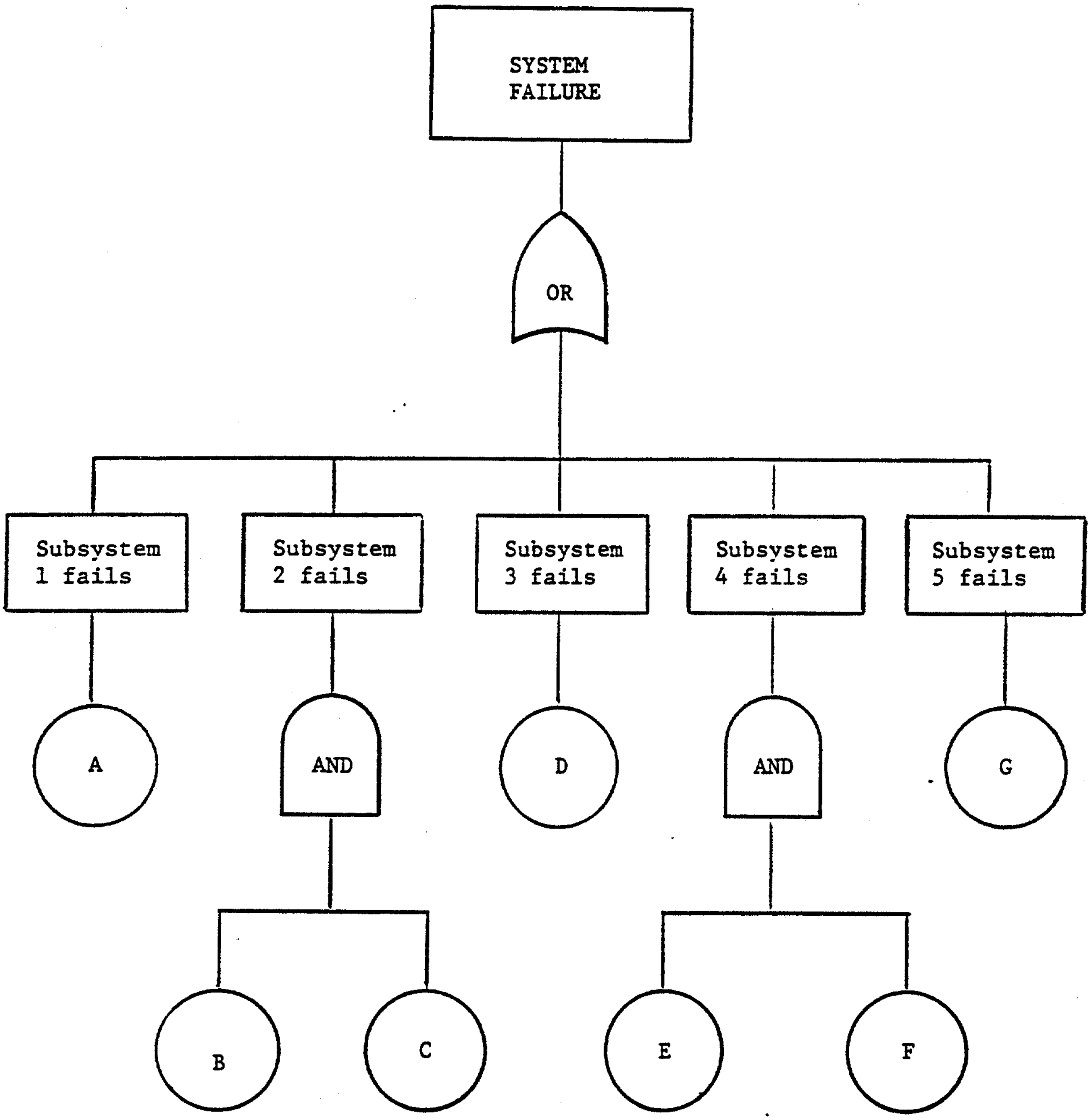
Finally, data availability is an important criterion in choosing a risk analysis method. If data on a risk is widely available, such as for workplace accidents, formal methods may not be necessary to analyze it. Formal methods might only be necessary if one needed to understand the less-frequent causes of such accidents, such as the circumstances leading to a blowout.

It is difficult to demonstrate empirically that risk analysis works. Usually, the results of a risk analysis are accepted and the high-risk areas are modified before an accident occurs, or, if the risk analysis is ignored and accidents occur as predicted, the risk analysis is not made public. An interesting example of the application of formal analytical methods in industry is the case of the Boeing 747, the first commercial airliner to have been designed and built making extensive use of reliability analysis. Unlike previous airliners, which had high accident rates during their first years of operation, the 747 did not have its first accidents for several years, and these were collisions rather than mechanical failures. (Rasmussen, 1982)

Companies in the U.S. that perform risk analyses rarely publicize them, partly over fear of liability for damages due to any hazards that were identified but not corrected. (Drake, 1982) (See also chapter 5 of this report.) However, there is evidence that risk analysis can help to identify high-risk areas. According to Drake, companies have rejected risk analyses performed for them because the most likely failure modes were thought to be implausible, only to experience the kinds of accidents that were predicted within a few of years.

Organizations such as NASA, the Nuclear Regulatory Commission, and an increasingly large number of companies use various forms of risk and reliability analysis as standard procedures, suggesting that such methods have proven useful to them. It makes intuitive sense that analyzing a system helps to locate and understand its failures and to make improvements. Although a rigorous proof is impossible, the evidence suggests that probabilistic risk analysis in its various forms is useful in designing and operating engineered systems. Like other types of engineering analysis, it provides useful, but not perfect, information to those who must make decisions at many levels of complexity and responsibility.

Figure 2.1 A Fault Tree



A,...,G indicate failures of components A to G

Modified from Henley and Kumamoto (1981, p. 300)

Figure 2.2 Event Tree for a Gas Leak

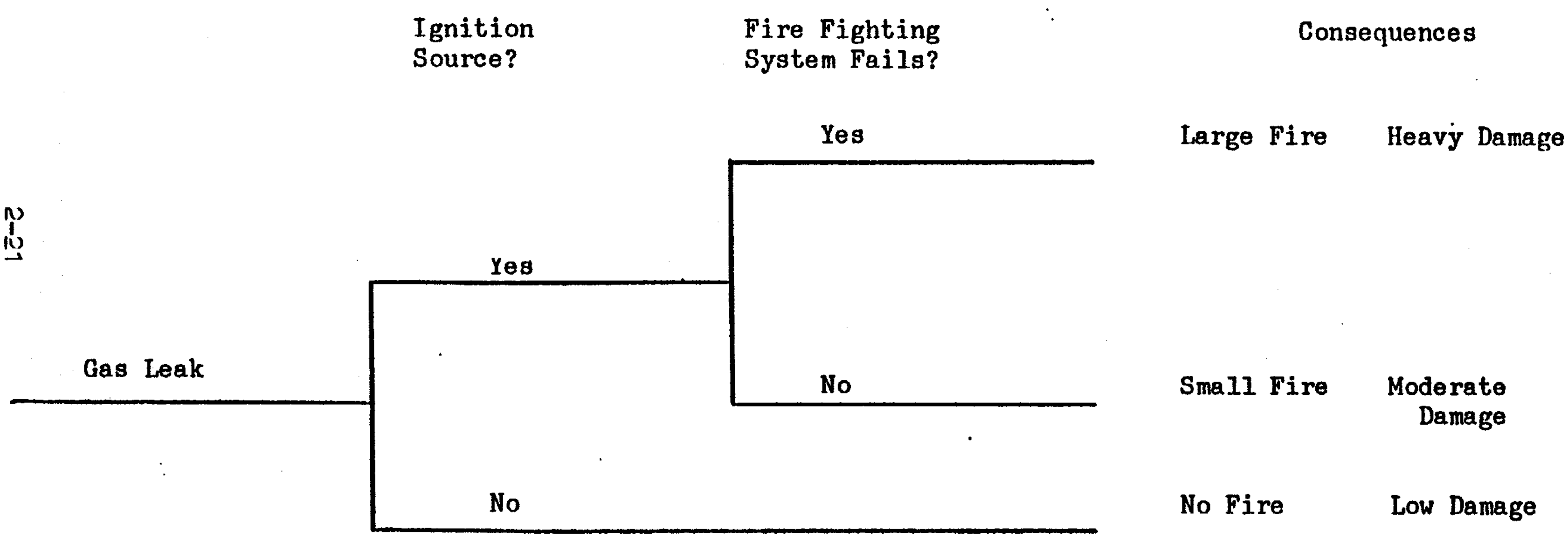


Figure 2.3 A Cause-Consequence Diagram

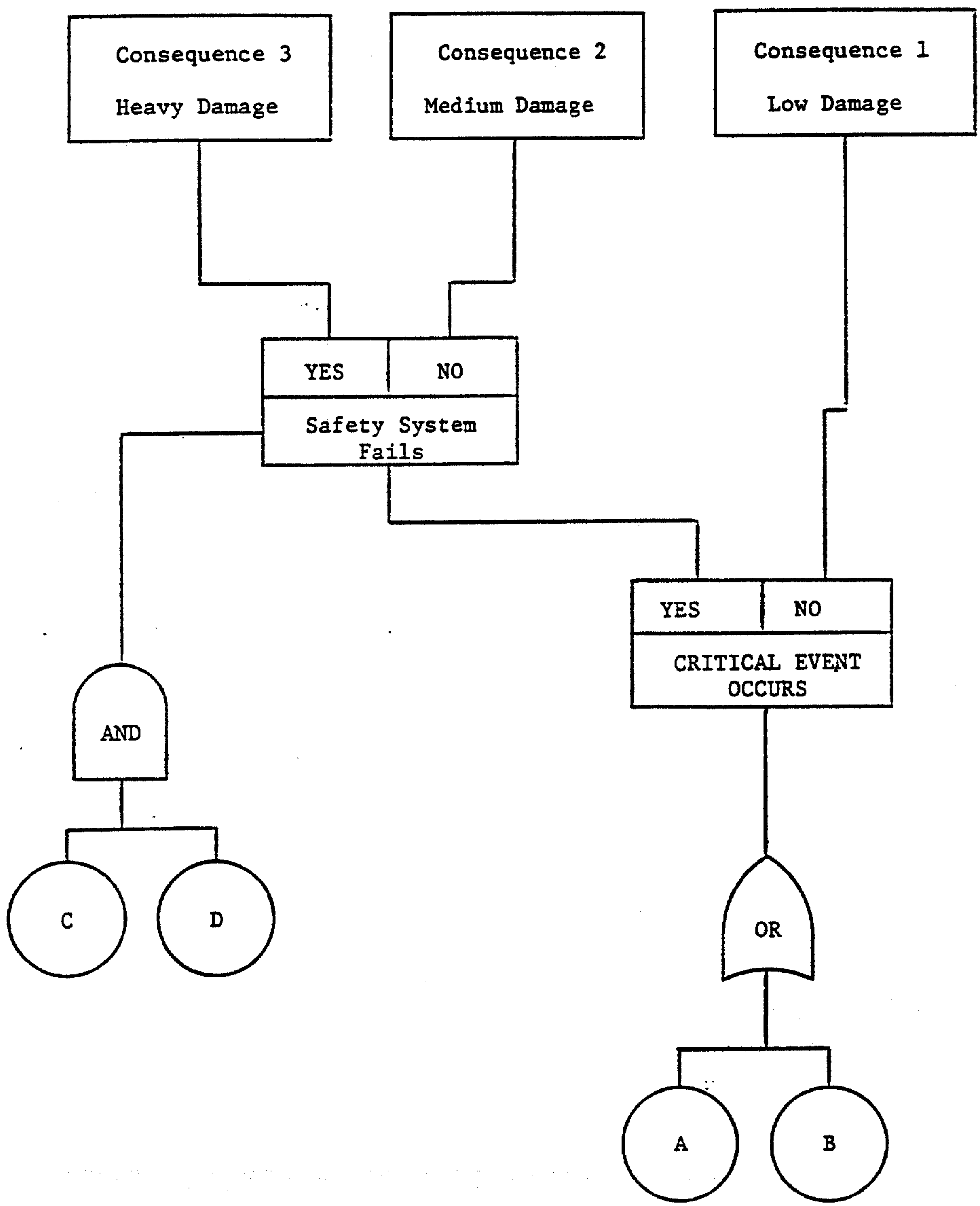
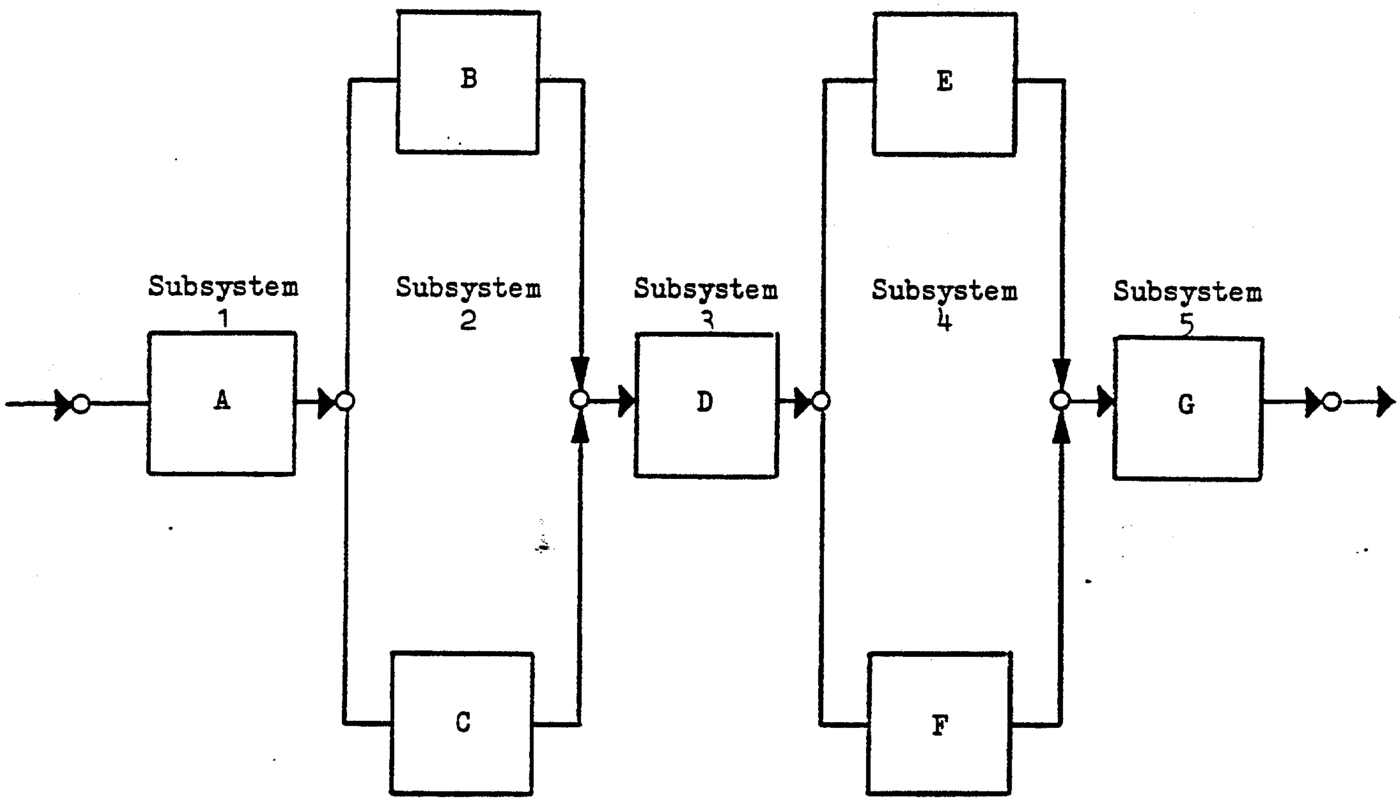


Figure 2.4 Reliability Block Diagram



A to G indicate the non-failures of components A to G

(Based on Henley and Kumamoto, 1981, p. 301)

Figure 2.5 Format for FMEA
(Failure Modes and Effects Analysis)

FORMAT FOR FMEA

Identification No.	Component	Function	Failure Mode	Redundancy	Critical Effect
Name the system on the schematic. Use code letters for the system. Number each component on the drawing. Use the code symbol for the system and the number of the component.	List the name of the component, its manufacturer and part number.	Describe briefly the function of the component.	List the ways in which the component can fail.	List the component which can supply or accommodate the function of the identified component should it fail in the mode indicated.	List the effect which the particular failure can produce, assuming its redundancy is adequate.

Source: Franz, Pish, and Vanzant (1973) .

CHAPTER 3

OFFSHORE RISK MANAGEMENT ACTIVITIES IN NORWAY AND THE UNITED KINGDOM

3.1 THE VALUE OF CROSS-COUNTRY COMPARISONS IN POLICY ANALYSIS

This study made extensive use of comparisons of the situation in the United States with circumstances and activities in other countries. Some have objected that other countries are different from the U.S., and that to look to them for guidance is misleading. They argue, correctly, that the culture, values, history, and geography of the other countries is different from that of the United States.

On the other hand, experience has shown that in a variety of domestic policy areas, a great deal can be learned from other countries, regarding both what might and might not work. Often, other nations' experiences are the only testing ground available for examining how alternative policies function, however imperfect this test might be. Furthermore, wisdom is not a uniquely American attribute, and other nations have invented approaches that are better than those that have been tried here.

Cross-country comparisons do pose problems. It is easy to become an "instant expert" on another country, or to listen to only one side of a question, and to obtain a biased view of the circumstances there. Furthermore, other countries really are different, and one must remain ever cognizant of this fact in interpreting their experiences and in offering recommendations for the U.S. based on inadequate understanding of the differences. Finally, it is an error to assume that what other nations _are doing_ is what they think they _should be doing_, and one must be sure not to recommend that a path be taken in the U.S. which the exemplar is at the same time abandoning.

With these caveats in mind, this chapter presents an interpretation of the offshore risk management activities of the two countries we visited, Norway and the U.K., and contrasts them with those of the U.S. To provide a sense for the context of risk management activities in the two countries, this chapter also describes the offshore energy developments there and discusses their R&D support programs. This chapter also includes a summary of the risk analysis activities in the two countries as applied to offshore energy development. Additional details of particular risk analysis activities in all three countries are presented in Chapter 4.

Much of the material in this chapter is based on our interviews overseas during January of 1983. We promised anonymity to our interviewees, so we cannot provide citations for many of our observations. A list of the individuals and institutions we visited is in the Appendix to this report.

3.2 OFFSHORE RISK MANAGEMENT IN NORWAY

3.2.1 The Offshore Energy Context

3.2.1.1 Introduction

In a period of less than two decades, petroleum exploration and production activities have become the preeminent factor in the Norwegian economy, displacing older industries such as fishing and ship building. Norway proclaimed sovereignty over the Norwegian continental shelf in 1963, and three years later the first exploration well was spudded. By 1975 Norway had become a net exporter of petroleum, and in 1983 production amounted to eight times the domestic consumption of petroleum. The Norwegian government has estimated that the oil sector's percentage share of the gross national product had risen to over 17 percent, and that oil and gas exports (including pipeline transmission) was 36 percent of total exports in 1983 (Royal Ministry of Petroleum and Energy, 1984.)

The Norwegian Petroleum Directorate (NPD) has estimated probable recoverable reserves on the Norwegian continental shelf south of the 62nd parallel at about 5.0 billion metric tons of oil equivalents (toe). Initial recoverable reserves proven by drilling are estimated at 3.6 billion toe. Of this amount, about 333 million toe have been produced as of April 1984. Proven reserves north of the 62nd parallel are about 0.2 billion toe (Royal Ministry of Petroleum and Energy, 1984.)

In the relatively short period of time that petroleum achieved such major national importance to Norway, new laws, regulations, and social contracts were formulated, and new technologies and systems were learned. Notwithstanding the rapid changes required of Norwegian society, the apparatus and bureaucracy concerned with controlling the activities of the new petroleum industry have developed in the context of a strong national consensus on rational exploitation of the petroleum resources, workers' rights, and environmental protection.

Allocation of offshore licenses has been a central regulating instrument by which the Norwegian government has influenced the level of petroleum activities and maintained a moderate and even rate of production. The first licenses on the Norwegian continental shelf were awarded in 1965. Seven additional licensing rounds have been completed by 1983. Initially, Norwegian companies lacked the required competence for an active role in petroleum activities, and foreign companies dominated the licensing. However, since the establishment in 1972 of Statoil, the state-owned oil company, the Norwegian share has steadily increased. Currently Statoil is allocted 50 percent of each production license. Foreign companies still play an important role in Norwegian petroleum activities by providing breadth to the technical community of the industry and adding to the needed capacity which cannot be met by the domestic industry alone.

Leases on the Norwegian continental shelf are not acquired by a bidding process. Instead, the Norwegian government decides which applicant firms shall be awarded leases. The main criteria by which the government selects companies as participants in licenses on the Norwegian continental shelf are:

i. that the applicant has sufficient experience to participate in offshore petroleum activities in a safe manner;

ii. that the applicant has sufficient financial strength to meet all obligations;

iii. that the applicant has the will to carry out thorough exploration of the licensed area;

iv. the sliding scale offered by the applicant for Statoil's participation;

v. the degree to which the applicant contributes to strengthening the Norwegian economy, industrial growth, and employment; and

vi. the previous activity of the applicant on the Norwegian continental shelf, including the extent to which the applicant has made use of Norwegian goods and services.

In addition to Statoil, other operators licensed on the Norwegian continental shelf are listed in Table 3.1.

TABLE 3.1

OPERATORS LICENSED ON THE NORWEGIAN CONTINENTAL SHELF

Amoco Norway Oil Company
BP Petroleum Development Ltd., Norway
Conoco Norway Inc.
Elf Aquitaine Norge A/S
Esso Exploration and Production Norway Inc.
Norsk Agip A/S
Norsk Hydro a.s.
A/S Norske Shell
Norwegian Gulf Exploration Company A/S
Phillips Petroleum Company Norway
Saga Petroleum a.s.
Total Marine Norsk A/S

Compared with other oil-producing areas of the world, it is well known that the North Sea poses relatively severe operating conditions. In addition to hostile weather and sea conditions, challenging drilling and safety problems result from high production flow rates and well-head pressures. These technical factors have coupled with the political system and societal structure in Norway to influence the development of unique management and administrative procedures and systems.

Governmental management of offshore activities in Norway began with the widely accepted use of certifying agencies. However, beginning in 1979, the fundamental principle underlying Norwegian regulation of offshore petroleum activities for fixed installations has been the concept of "internal control"; regulation of mobile installations remains under the older system of certification. Under the system of internal control, the licensee is directly responsible, and carries unlimited liability, for the safety and quality of the project. Rather than supervise compliance with a specific list of operating regulations, the main function of governmental authorities is to review the safety and quality systems proposed and carried out by the licensee. This system is perceived by many to be more burdensome to the operator than direct requirements for compliance with specific operating regulations. On the other hand, more freedom is generally available within this system for using innovative or untried approaches that might be unique to the operator or the facility. The role of internal control in the Norwegian system of offshore safety management is discussed more fully in Section 3.2.3.

3.2.1.2 Working Conditions Offshore

The traditionally strong place of the worker in Norwegian society has influenced the development of the Norwegian approach to offshore safety management. Legislation for the protection of labor was first introduced in Norway in 1892. Since then, a series of labor laws has been enacted, the most comprehensive being the currently applicable Worker Protection and Working Environment Act of 1977. In general, the employer is responsible for providing a working environment that provides employees with full safety against harmful physical and mental influences. In addition, specific provisions of the law give employees influence over matters concerning the working environment. Based on the recognition that offshore activity is not directly comparable with onshore industry, a Royal Decree was issued in 1979 specifying which sections in the 1977 law are not applicable offshore.

The Norwegian Directorate of Labor estimates that a total of 52,170 workers were employed in petroleum activities in 1983. All workers on the Norwegian continental shelf are unionized. In-house unions have been formed on fixed installations operated by Phillips Petroleum, Mobil Oil, and Elf Aquitaine. Workers on all other fixed installations are organized under NOPEF, the Norwegian Oil and Petrochemical Workers' Union.

3.2.2 Implementing Legislation for Offshore Safety Management

Following gas discoveries in the waters of The Netherlands and Great Britain, offshore activity in Norway was initiated when, in 1962, the Phillips Petroleum Company requested the sole right of exploration and exploitation of hydrocarbons on the Norwegian continental shelf. No legislation, no administrative apparatus, and little local knowledge of oil and gas exploration and production existed in Norway to provide the basis of a response to the Phillips request[1].

As a first step, a Royal Decree was issued in May 1963 stating that the continental shelf off the coast of Norway belonged to the Kingdom of Norway. With this basis, agreements were subsequently reached with the U.K., Denmark, and Sweden that defined the territorial lines in the North Sea south of the 62nd parallel. Some questions concerning the lines north of this parallel are still unresolved, however. The main laws, regulations, and guidelines governing activities on the Norwegian continental shelf are presented in a publication written in both Norwegian and English by the NPD (Norwegian Petroleum Directorate, 1983.)

One month after the 1963 proclamation, the Storting (Parliament of Norway) issued a law vesting in the State the rights to the subsea natural resources. This new law permitted the government to give the rights of exploration and exploitation of the resources to domestic and foreign persons and organizations, and allowed the government to issue regulations concerned with the exploration and exploitation of subsea natural resources.

Since exploration and drilling regulations were most urgently needed at that time, it was felt that rules governing production could be postponed. A second Royal Decree issued in August 1967 was related to safe practices in exploration and drilling for subsea petroleum resources. This extensive law was expanded and revised in October 1975, and it currently serves as the framework for the regulation of mobile installations. For example, the 1975 Decree specifies that equipment should be chosen so as to minimize the risk of accident, fire, and explosion, and that wells should be secured properly in accordance with good and careful oil industry practices. Based on its authorization of the responsible governmental agencies "...to issue further regulations and orders as needed for implementation of the Decree...," detailed supplementary regulations have been issued that expand the general requirements of the 1975 Decree (Norwegian Petroleum Directorate, 1983.)

Since offshore activities cover a broad range of regulatory concerns, compliance with the 1975 Decree is supervised by a number of governmental agencies. In the case of mobile installations, the Maritime Directorate is responsible for coordinating the controlling agencies listed in Table 3.2. Detailed supplementary regulations have been issued by each of the controlling agencies, while enforcement of the regulations is managed for the most part through third-party certification agencies. A comprehensive internal control system for the range of worldwide operation of concern to the Maritime Directorate is not considered appropriate, although regulations for an internal control system for mobile platforms are currently being considered for a proposed new law.

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[1] This request was denied by the Norwegian authorities, although Phillips later became a licensed offshore operator in Norway.

TABLE 3.2

NORWEGIAN GOVERNMENT AGENCIES SUPERVISING
MOBILE OFFSHORE INSTALLATIONS

Norwegian Maritime Directorate - Coordinator
Norwegian Petroleum Directorate
Norwegian Water Resources and Electricity Board
Directorate of Public Health
Norwegian Telecommunications Administration
Directorate of Civil Aviation
National Inspectorate of Explosives and Flammables
Norwegian Directorate of Seamen
State Pollution Control Agency

Fixed installation are regulated through a Royal Decree issued in July 1976, which is concerned with safety rules for production of petroleum resources under the seabed. The Norwegian Petroleum Directorate is designated as the coordinating agency for fixed installations. The controlling agencies for the 1976 Decree are listed in Table 3.3, along with their areas of responsibility. (Andersen, et al., 1983)

The two main functions of the NPD concern resource management and offshore safety. In order to separate economic and safety interests, the NPD functions organizationally under and reports to two separate ministries within the Norwegian government: the Ministry of Petroleum and Energy, and the Ministry of Local Government and Labor.

As in the case of mobile installations, the underlying regulations governing fixed installations are general, giving the controlling agencies the authority to issue more detailed regulations as needed. Prior to 1979, certification agencies were used in the regulation of fixed offshore installations. For the most part, however, unlike the detailed supplementary regulations issued for the control of mobile installations, since 1979 control of fixed installations has been based on the system of internal control, in which the regular flow of information between the licensee and the controlling agencies is emphasized to ensure acceptability of technical solutions.

TABLE 3.3

NORWEGIAN GOVERNMENT AGENCIES SUPERVISING
FIXED OFFSHORE INSTALLATIONS

Norwegian Petroleum Directorate	Telecommunications Administration
- Load-bearing structures - Pipelines - Shipment installations - Drilling equipment and procedures - Platform arrangement - Pressure vessels and systems - Machinery and utility equipment - Electrical installations/aids area classification - Passive fire protection - Gas detection and alarm system - Fire detection and alarm system - Emergency shut-down system - Emergency power - Emergency lighting - General equipment and inter-communications - Cranes, ladders, and rails - Living accommodation - Diving operations, diving equipment, and required qualifications for divers - Transportable pressure chambers - Emergency power arrangements in connection with diving operations - Worker protection and working environment	- Telecommunication systems **Coastal Directorate** - System and equipment for marking and identification - Maritime radio position finding - Electric emergency power arrangement for the system for which the Coastal Directorate is responsible **Civil Aviation Administration** - Flight operation conditions **Ministry of Environment/ State Pollution Control Agency** - Waste disposal procedures - Equipment and procedures for cleaning of substances which may lead to pollution of the environment
Maritime Directorate	**Ministry of Social Affairs/ Directorate of Public Health**
- Life-saving equipment and its location, as well as launching arrangements for lifeboats - Life-saving drill	- Hygienic conditions - Medical office and sick bay with furnishing, fitting, and equipment - Health checks - Drinking water supplies - Comfort standard in ventilation and heating

Some detailed regulations remain in effect from the earlier system of regulation, although they are included under the internal control system. These include regulations for:

i. the structural design of structures;
ii. cranes on production installations;
iii. production and auxiliary systems on production installations;
iv. instrumentation, recording, and processing of environmental and platform data;
v. fixed means of access, stairs, ladders, and railings on production platforms; and
vi. the transfer of personnel to and from production installations.

Recognizing the special working environment offshore, a Royal Decree was issued in June 1977 that states which sections of the Workers' Protection and Working Environment Act of February 1977 are applicable offshore and that adds provisions specific to activities on the continental shelf.

Currently, a new petroleum law is in the legislative process in Norway. Two Royal Decrees will be contained within this new law - one concerned with resource management, and the second intended to replace the safety decrees of 1975 and 1976. The new law will bring the regulation of both mobile and fixed installations under the same coordinating agency, and it will provide a uniform framework for all offshore activities.

3.2.3 Safety Goals and Criteria

3.2.3.1 Introduction

The primary concern of the laws and regulations governing offshore activities in Norway is the safety of the worker. Somewhat less emphasis is placed on protection of the resource and of the natural environment. Official supervision of offshore activities is based on the principle of internal control, under which the licensee is responsible for ensuring that the facilities are designed, built, installed, operated, and maintained in accordance with the general official requirements and regulations. Included in the 1976 Decree relating to safe practices for production of subsea petroleum resources is the general provision that the NPD (as the designate of the Ministry of Industry and Handicraft) may require the licensee to carry out safety studies and analyses of the offshore activity. Guidelines issued by the NPD clarify the internal control task and give guidance for the execution of safety evaluations, both of which are required as part of the project approval procedures (Norwegian Petroleum Directorate, 1983.)

3.2.3.2 Internal Control

Internal control is an overall approach to risk management in which the operator, rather than a government agency or agencies has primary responsibility for defining, implementing, and overseeing a system to ensure that the operator's activities meet all relevant safety criteria. The government roles involve (i) establishing the broad safety criteria that operators must meet, (ii) oversight of operators' procedures, and (iii) random audits of operator compliance with these procedures; rather than promulgation and enforcement of compliance with detailed regulations, standards, and specifications.

The principle of internal control is derived from the two Acts relating to worker protection, and from the regulations relating to safe practices for exploration and drilling and to safe practices for production. These laws require that the licensee must establish and maintain an internal control system which ensures that work is planned, organized, and performed in accordance with the stated requirements. In all cases, governmental supervision is regarded as supplementary to the company supervision for which the licensee is responsible, and does not reduce or supercede the responsibility of the company.

Early in the approval process, the licensee must present to the NPD a general written description of the internal control plan; detailed descriptions must be submitted later at an agreed time. All work related to the facility is monitored within the operator's organization under the approved internal control plan. For the most part, the governmental controlling agencies monitor the activities of the operator through formal approval requirements and by audits of the operator's implementation of the internal control plan.

Prior to initiation of the requirements of internal control in 1979, the NPD required certification of fixed installations by certification organizations, such as Det Norske Veritas (DNV) or the American Bureau of Shipping (ABS). Under the new requirements, certification is not required, but the certification or other specialized organizations often act as technical consultants to either the operators or the governmental authorities. Certification is still required by the Norwegian Maritime Directorate for mobile offshore installations, although this requirement may be modified in the new petroleum law currently under consideration.

A schematic example of a systematic approach to managing an offshore installation based on internal control has been described by Killerud (1982). The total safety requirements incorporating the principle of internal control should include both the minimum requirements of the authorities and the requirements of the operator. In this case, risk control is achieved through preventive methods - reliability techniques, quality assurance, technological safety features, equipment, training, etc.; and corrective methods - technological safety features, equipment, contingency plans, etc. An important aspect of the safety management strategy is the feedback from operating experience with the facility to risk control on the facility. The flow of relevant information within the operator's organization, and between his organization and the controlling agencies, is implemented through the internal control plan. Although this approach may seem simplistic, it imposes strict requirements on the organization's operation and demands the expenditure of significant effort and resources for data collection and processing, structured risk analysis, and communication.

3.2.3.3 Approval Procedure

Two major approvals early in a project, a number of part approvals, and various permit approvals are required by the Norwegian authorities in the course of an offshore development project. (Hope, 1983) Common to each of these approvals is the requirement that the operator show that all aspects related to safety and quality assurance have been considered in accordance with Norwegian laws and regulations.

The initial approval for the development of a petroleum field on the Norwegian continental shelf is based on the submission by the operator of the Field Development Plan. Formal approval to proceed with the project is granted by Parliament on the basis of the recommendation of the Ministry of Petroleum and Energy on matters concerned with resources, and of the Ministry of Labor and Municipal Affairs and the NPD on technical and safety issues. The Field Development Plan contains sections concerning geology and reservoir characteristics, economic feasibility, and general technical aspects of the installation, as well as a description of the safety management approach for the project. The description of the safety management approach includes a discussion of safety policies, the internal control and quality assurance systems, and preliminary safety evaluations of alternative development concepts.

Near the end of the pre-engineering phase of the project, the operator must submit to the NPD an Extended Field Development Plan (know more commonly as the Main Plan). The Main Plan forms the principal basis for governmental acceptance of the project and is composed of technical descriptions of the various parts of the installation, emphasizing platform protection and monitoring through the internal control and quality assurance systems. Also required in the Main Plan is a major safety analysis of the platform concept[2].

The NPD carries out a complete review of each plan submitted by the operator, up to and including the Main Plan. Subsequent activities of the project are controlled by the NPD through the internal control system of the operator and through random technical and managerial audits of operators' activities and documents. There is now no formal system of third party certification of fixed installations in Norway, although certification societies may be incorporated by the operator in his system of internal control at his option.

3.2.4 Formal Risk Analysis

3.2.4.1 Concept Safety Evaluation

At the conceptual design phase of a fixed-installation offshore development project, the Norwegian Petroleum Directorate requires the operator

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[2] This "concept safety evaluation" is discussed in more detail in Section 3.2.4.1.

to submit a thorough safety evaluation as part of the Main Plan. The NPD guidelines for this concept safety evaluation are strongly oriented toward risk analysis methods, although alternative methods are not precluded (Norwegian Petroleum Directorate, 1983; Andersen et al., 1983.)

The purpose of the concept safety evaluation is to ensure that the effects of possible serious accidental events are considered at the earliest possible stage in the design in order to avoid expensive, safety-based major changes in the subsequent detailed design and construction phases of the project. In addition, within the concept safety evaluation a set of design criteria are developed that are based on "design accidental events" and that can be followed during the later phases of the project development. On the other hand, however, a concept safety evaluation done at the pre-engineering phase of a project may not be sufficiently detailed to identify all of the safety questions that might arise, and others may have to be addressed later.

The acceptance criteria for the concept safety evaluation in the Main Plan are based on the maintenance of acceptably low probabilities of the loss of human life, of large material damage, and of unacceptable environmental damage. Thus, for example, the adequacy of the platform design is measured by the ability of the escapeways, shelter areas, and main support structure to remain functional for a specified period of time during one or a combination of "design accidental events"; thereby permitting personnel outside the immediate vicinity of the accident to reach a safe location. Other criteria are concerned with the integrity of active protection measures and of control and monitoring functions.

The design accidental events are particular scenarios in which the consequences of an initiating event (e.g., a pipe rupture) are considered if it were to occur in combination with particular circumstances (e.g., unfavorable wind direction, protective system failure, etc.) Typically, five to ten such scenarios, which are intended to represent the most serious conceivable events, are considered.

Accidental events that must be considered include process failures, wellhead accidents, collisions, structural failures, and extreme environmental loadings. In the NPD guidelines, accidental events are classified into nine distinct accident types: blowout, fire, explosion, and similar incidents; falling objects; ship and helicopter collisions; earthquakes; other possible relevant types of accidents; extreme weather conditions; and relevant combinations of these accidents. The total frequency of occurence of accidental events which cannot be considered design accidental events because they would, for example, make all escapeways impassable, should not exceed about one in ten thousand per facility per year. The same criterion applies for shelter areas and the main support structure. These excluded, most improbable, events are termed residual accidental events. The residual accidental events are not the failure cases themselves; they are the failure cases in combination with other specific circumstances such as unfavorable wind direction or unusual wave height. We should note that the 10^{-4} frequency is intended by the NPD to be a rough guideline, not a rigid limit. Thus, the approximate nature of the quantitative analysis, the scarcity of appropriate data, and the judgments involved in setting the standard are all considered when comparisons with the standard are made.

In principle, within the given acceptance criteria, the designer is free to select which events are design accidental events and which are residual accidental events. Although not stipulated by the guidelines, the most suitable approach for selecting the design accidental events is to use risk analysis, since this technique recognizes the inherent probabilistic nature of offshore operations and allows for the inevitable residue of extreme events that cannot be completely eliminated in any practicable system.

The outcomes of the accidental events consider factors such as weather, ignition time delays, operator intervention, and protective system operation. Behavior of the installation is based on the consequences of the accidental events, which are normally expressed in terms of heat flux and duration; impact pressure, impulse, or energy release; and acceleration.

In addition to the required comparison of the response of the system with the NPD guidelines, a valuable feature of the concept safety evaluation is the resulting specification of clearly defined cases which can be used in a conventional design process. Thus, an engineering appraisal of the planned system is provided which focuses on a design that will meet the highest standards of safety performance. Indicated behavior of the platform that does not satisfy the requirements of the guidelines leads directly to design changes, making the design an iterative process with the concept safety evaluation.

About a dozen concept safety evaluations have been completed in Norway, mostly for submission to the NPD. Subjects of study have included major integrated platforms incorporating drilling, production, and living quarters with steel and concrete structures; small riser platforms; a major water injection, drilling, and living quarters platform; advanced deep water concepts; and semisubmersible platforms. There is general agreement among industry, consultants, and governmental authorities in Norway that the concept safety evaluation requirement promotes a rigorous consideration of the safety of proposed installations at their formative stages, and that it provides a reasonable basis for design.

3.2.4.2 Model for Safety Management

As part of the research program SPS (see Section 3.2.5), a comprehensive model for safety management has been developed in cooperation with government agencies and ten petroleum companies (Hope, 1983.) The resulting model provides a detailed framework for an offshore development project, with emphasis on the activities concerned with safety management. Major items shown in the model include the project phases, tasks and analyses performed, documents prepared, decisions made, and the roles of the project participants. Although the NPD does not require this particular framework to be adopted by the operator, the model does provide all the essential features which would be acceptable for satisfying the government guidelines for the internal control system, the Main Plan, and the documentation of safety analyses.

3.2.4.3 Collection of Offshore Reliability Data

Seven oil companies operating in Norway have participated in a joint project to collect and publish reference reliability data for offshore drilling and production equipment and safety systems. Based on data gathered from the records and experience of the participating companies, the OREDA Handbook (OREDA, 1984) provides generic reliability information which can be used in safety and reliability/availability studies of offshore systems. For each item covered in the handbook, quantitative information is presented on failure modes; failure rate for each failure mode, including associated uncertainty limits; mean repair time, including active repair time and manhours; and supportive information, including number of events, time in service, and population. In addition to providing data for reliability and safety analyses, the handbook can serve also as a model for data collection and analysis within a particular company. Subsequent editions of the handbook can be expected as data collection continues and additional companies join the project.

3.2.5 Research and Development

Based on a 1978 Royal Decree, Norwegian authorities, oil companies, and research institutions initiated major research and development programs concerned with the risks of offshore oil and gas activities. The Ministry of Local Government and Labor allocated 60 percent of the funds to the Royal Norwegian Council for Scientific and Industrial Research (NTNF) to administer the research program entitled "Safety Offshore" (SPS). The remaining 40 percent of the funds were allocated to the Norwegian Petroleum Directorate (NPD), which managed two research programs entitled "Safety, Procedures, and Monitoring" (SPO) and "Contingency Planning" (SSB).

The SPS program, extending for a period of five years until 1982, was the largest civil research program ever conducted in Norway. The government contributed NOK 64 million ($9 million) and industry contributed NOK 49 million ($7 million) to sixteen research institutions and sixteen firms, which conducted 176 projects. (Kaarstad and Wulff, 1984) The SPS program was concerned primarily with risks to human beings, with environmental and economic risks being secondary. The results of this effort are documented in over 500 separate reports listed by title in the Appendix of Safety Offshore by Kaarstad and Wulff. Most SPS reports can be ordered or located through NTNF. At the conclusion of the SPS program, responsibility for offshore safety research was taken over by the Continental Shelf Committee of NTNF. Research will continue at a considerably more modest funding level in such areas as risk analysis and safety management, human aspects, mobile platforms, contingency preparedness, diving and underwater operations, fire, drilling and production, and training.

The objective of the SPO program was to investigate areas of preventive safety measures related to the activities and responsibilities of NPD. Over a three and one-half year period, NOK 13.5 million ($1.92 million) was contributed by the government and NOK 3.1 million ($0.45 million) by industry to conduct research projects to examine the safety built into installations and systems, the man-machine relationship, and the procedures and administrative activities aimed at avoiding accidents and dangerous situations. Specific projects represented high priority problem areas for the NPD, including drilling, construction, safety, production, information systems, and diving. Most of the reports from SPO projects are available through the NPD or the various research institutions.

The SSB program extended over a three and one-half year period, with total contributions from the government of NOK 12.6 million ($1.8 million) and from industry of NOK 11.7 million ($1.67 million). Within the concerns of contingency planning the main areas of research included preparedness systems, evacuation and medical preparedness, diving, and protection of wells and limitation of damage from blowouts. Reports from SSB projects are available from the NPD.

3.3 OFFSHORE RISK MANAGEMENT IN THE UNITED KINGDOM

3.3.1 The Offshore Energy Context

The discovery and development of offshore oil and gas has been a revolutionary development in the modern United Kingdom. While its initial industrialization was based on water power and coal as major sources of energy, during the 20th century Britain had become a major importer of oil and oil products, and thus heavily dependent on imports for its economic well-being. The country had no significant domestic production of oil and gas until the mid-1970's, yet by 1981 the U.K. had actually become self-sufficient in petroleum and had become a modest net exporter of crude oil. (Nevertheless, the U.K. is also a substantial importer of petroleum and refined products since its refinery capacity is too small to meet domestic demands for refined products.)

Total production of offshore oil in the U.K. in 1983 amounted to 115 million tonnes, worth 17.5 billion pounds sterling, or about $23 billion[3]. Production of natural gas totaled 39.5 billion cubic meters worth about 1.1 billion pounds, or about $1.4 billion. In that year, offshore energy production accounted directly for about 5% of GNP in the U.K. and for about 28,700 jobs on installations. Many thousands of other jobs in the U.K. can be traced to offshore energy activities. Roughly 27% of all U.K. industrial investment in 1983 was directed toward the offshore oil and gas enterprise. Clearly, offshore energy has become essential to the economy of the United Kingdom on a scale that far exceeds its importance to the U.S., where offshore oil and gas contribute only from 1/2 to 3/4 of one percent of GNP.

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[3] Energy and other data in this section for the U.K. are taken from the "Brown Book" of the U.K. Department of Energy (1984).

The offshore energy producing fields of the U.K. typically lie 50 miles or more from the nearest coast, so they pose a less immediate danger to coastal areas and to tidewater fisheries than do many U.S. offshore fields. The offshore environmental effects are less tangible to citizens and officials in the U.K. than in the U.S. This fact, combined with the great importance of offshore energy to the nation's economy, has lessened the concern for environmental hazards of offshore activity as compared with the U.S. In fact, for example, safety analyses in the U.K. sector focus almost entirely on possible loss of life and property and pay little or no attention to possible environmental damage.

On the other hand, offshore energy development has had very great impacts on the adjacent coastal communities, and these have been the focus of considerable public concern. Old fishing and industrial cities of the northeastern British Isles, such as Aberdeen in Scotland, have become bustling boom towns, with some of the social and economic challenges that sudden growth can bring.

From an employment point of view, offshore energy development has been viewed as a major creator of new jobs in a region that has faced severe losses of jobs in other industries. In addition, the energy independence that the U.K. now enjoys has enabled it to weather what might have been even more severe recessionary pressures during recent years. On the debit side of the ledger, the British pound is considerably stronger than it would otherwise be in international markets due to oil revenues, and this has caused a decline in the export performance of other sectors and a simultaneous increase in imports that compete with them on more favorable terms. This factor has exacerbated the high unemployment problem of British industry in general, even though the government's oil revenues have helped to meet the needs of the population negatively affected by the strong pound. In 1983, government revenues from royalties, fees and taxes on offshore oil amounted to 9.0 billion pounds, which is equivalent to nearly 60% of the total revenues from the value added tax and to over one-fourth of the total income tax revenues of the nation. Royalties accounted for about one-fifth of the total government offshore energy income and taxes for the rest.

Offshore work is widely viewed as demanding and hazardous, due in part to the range of hazards that any sort of work threatens in the hostile North Sea and in part to the fact that most workers are resident on the rigs for two-week shifts due to the great distances from operations to shore. The cyclic nature of demanding work strains the personal lives of workers, who are experiencing high rates of family crisis, alcoholism, and the like.

The U.K. sector of the North Sea has been relatively free of major disasters, but it has experienced a high aggregate loss of life, especially during the early years when exploration dominated offshore activities. Now that the activity offshore has shifted toward the inherently safer production phase and as operators have learned better how to cope with offshore hazards, the incidence of loss of life has declined in absolute terms and dramatically as a ratio to total production. The incidence of loss of life in the U.K.

sector has declined from roughly one death per 1 million barrels produced (a total of 10 deaths) in 1975, to roughly one death per 85 million barrels produced (a total of 10 deaths) in 1983 attributable directly to offshore oil and gas production[4]. To get a somewhat different perspective, the rate of offshore fatalities in the U.K. was one per 630 workers employed in 1975, the first year of oil production, and had declined to one per 2,900 workers employed in 1983. The actual number of deaths varies widely by year, and has ranged in recent years from a low of 6 per year to a high of 17.

In contrast to concern for worker safety and the integrity of offshore installations, environmental problems of offshore activities have been of lesser concern in the U.K. This is in part a consequence of the fact that most of the activities take place rather far off shore where routine losses of oil do not do much damage. Futhermore, it is felt that attention to the safety risks of rig malfunctions will serve to protect the environment as well. According to one company engineer with whom we spoke, environmental damage is not a factor in rig design; presumably this means that controls now in use are felt to be adequate. On the other hand, there is substantial concern for the onshore impacts of coastal operations related to offshore activities. However, these impacts lie outside the scope of our study, and we made no systematic attempt to understand how they are managed by a combination of local and national authorities in the U.K.

As in the U.S., the offshore energy resources on the continental shelf are public property, held on behalf of the people by the Crown and leased to private and state-controlled operators for exploration, development and production. Operators offshore include such U.S. and European multinational oil firms as Exxon, Shell, Conoco, Mobil, Amoco, Texaco, and Phillips, along with the British firm, British Petroleum (BP), and the British National Oil Company, BNOC.

Originally, BNOC was set up to manage the offshore resource on behalf of the government, and to market the oil that the government generally accepted from the operators in lieu of lease payments. More recently, the oil-producing activities of BNOC have been sold to the private sector, and BNOC remains as a state-owned firm marketing the government's oil.

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[4] These rates of fatalities are estimated from data reported by the U.K. Department of Energy (1984) by dividing total oil production by the number of reported fatalities. This procedure attributes all deaths to oil alone and none to gas, and it omits all deaths experienced in associated transportation and shipping activities, which exceed in total the deaths at offshore operations per se in some years. For example, in 1981, 17 persons were killed in associated transportation activities, while only 6 were killed in oil and gas operations.

3.3.2 The British Government's Role in Offshore Safety Management

3.3.2.1 Organizational Framework

As in the U.S., responsibility for regulating the safety and environmental aspects of offshore development in the United Kingdom is divided among several agencies. This division of responsibility has been the subject of considerable controversy there, and was recently changed to reflect the recommendations of the Burgoyne Committee. (Burgoyne, 1980)

The Petroleum Engineering Division (PED) of the U.K. Department of Energy (UK DOE) has primary responsibility for regulating offshore operations. The Division is in turn divided into several branches that share responsibility for such matters as structural safety, personnel safety, and research and development. The PED has three funtional inspectorates: the Petroleum Inspectorate, the Diving Inspectorate, and the Pipelines Inspectorate. A total of 22 inspectors were employed by the inspectorates at the time of the Burgoyne report in late 1979. The primary responsibility of the PED has been to oversee the overall structural integrity of offshore installations and the safety of operations.

The Burgoyne Committee had as its principal charge the making of recommendations regarding "...the nature, coverage, and effectiveness of the DOE's [safety] regulations governing the exploration, development and production of oil and gas offshore and their administration and enforcement." More specifically, however, the Committee was concerned with the question of whether the DOE or the Health and Safety Executive (HSE) should be in charge of enforcing the provisions of the 1974 Health and Safety at Work Act insofar as they pertain to the offshore. There were strong arguments and politically-held positions in favor of each alternative. The argument in favor of DOE enforcement was that the DOE/PED inspectors were already routinely on site at offshore installations and that they therefore had both access and the technical expertise necessary to assess hazards in this highly specialized realm; aspects of the enforcement process that HSE did not possess. The counter view was that the DOE was concerned first with ensuring the production of energy offshore and that it necessarily had a conflict of interest in pursuing a safety objective that sometimes conflicts with maximum production. Furthermore, the HSE was presumed to have greater expertise than the DOE in the area of general hazards to workers . Over the objections of some of its members, particularly those from organized labor, the Committee recommended that DOE/PED retain the safety regulatory role, which then was adopted as policy. Under this arrangement, the Department of Energy enforces regulations related to worker safety and health on behalf of the Health and Safety Executive. Following the compromise, the HSE transfered four safety inspectors to the DOE.

Under the Burgoyne compromise, the HSE retains the right to advise the Secretary of State for energy regarding offshore safety, and the HSE and its parent Health and Safety Commission must always be consulted by the DOE concerning proposed changes in policy regarding offshore safety. Furthermore, the HSE continues to be advised by an official Oil Industry Advisory Committee that includes members from both industry and labor.

An important provision of the Health and Safety at Work Act that applies offshore is that workers in each place of work have a right to select one of their number as a safety representative in dealing with employers. Organized labor, if present, is charged with this selection; otherwise, it is up to the workers themselves.

3.3.2.2 Legislative Framework

The basic framework for U.K. control of both the resources and the operations in the sea was established in the Continental Shelf Act of 1964, which was in turn adopted pursuant to the 1958 U.N. Conference on the Law of the Sea that established the rights of states to the natural resources of their continental shelves. The 1964 act extended to the offshore the 1934 Petroleum Production Act, which enabled the granting of licenses and the making of regulations pertaining to the exploration and exploitation of petroleum.

In 1971 a new act was passed, the Mineral Workings (Offshore Installations) Act, which applies to the exploration and exploitation of mineral resources under territorial waters or in areas designated under the 1964 Act when the activities are from installations not connected to dry land. That is, it applies to activities from such installations as drillships, jack-up rigs, semi-submersibles or fixed platforms. This Act enables regulations to be made regarding the safety of offshore installations and the safety, health and welfare of persons aboard. A large number of regulations have been made regarding such matters as the registration of installations; the design, construction and operation of offshore installations; appointment of installation managers with responsibility for the safety, health, and welfare on installations; the appointment of inspectors and the reporting of accidents; diving operations; and emergency procedures and equipment. (The Burgoyne report (1980) summarizes the history and details of these regulations).

The Construction and Survey Regulations of 1974 are probably the most important of the regulations in establishing the basic regulatory philosophy and approach. Under these regulations, no fixed or mobile installation may operate on the U.K. continental shelf unless it has a valid Certificate of Fitness issued by an independent certifying authority. Such certificate must state that the design is suitable for the intended use and that the installation has been properly constructed in accordance with the design. According to the Burgoyne report, "The concept of these regulations is that an independent expert body should have a continuing role overseeing the construction and mode of operation of all offshore installations. The Certifying Authority is thus involved at the design stage, the construction stage and by means of the periodic surveys required by the regulations, during the operational life of the installation." Thus, these regulations represent an extension into the realm of offshore energy activities of a mode of regulation that has been used in the maritime arena for many years -- namely, the dependence on an outside authority for certification.

The use of external certifying authorities is an unusual aspect of offshore safety regulation that reflects the unique problems of controlling safety on the high seas. Historically, the certification societies are associated with the insurance practices of ship builders and owners. In fact, one of the oldest and largest of the certifying authorities is Lloyds of London, which is associated with the insurance market of that name. In order to qualify for the insurance that is needed to obtain financial backing for building ships and for taking responsibility for their cargoes, ship owners must obtain a certificate of fitness based on both the ship's design and its ultimate construction. The expense of this certification is typically borne by the ship's financial backers, but it must be accepted by the insurers. Parties to such contracts for ship financing are free in principle to seek certification anywhere, but certifiers who give their stamp of approval to unworthy designs or inadequate construction and maintenance would soon have no business since insurers would not accept their certificates.

More recently, government regulators have found it efficient to adopt the same certification procedure in deciding whether a vessel is safe, so long as the certifying agents use the government's standards as the minimum that they will accept. Government agencies, such as the U.K. PED and the U.S. MMS, maintain lists of certifying agents whose approvals they recognize. Some such agents are qualified to certify every aspect of a vessel or rig, while others are limited to certain aspects, such as cranes. The major concern of certification relates to the fitness of offshore installations, and focuses on the fitness of the structure to withstand the loads it may face. Such certification must be updated annually, which requires a periodic inspection of the installation by the certifying agent.

Offshore installations in the U.K. North Sea are inspected periodically on an unannounced basis by inspectors of the DOE PED. While in the early days of North Sea development rigs were inspected annually, the Division's policy has shifted to inspecting more frequently those installations with the poorest safety records and vice versa. Installations under construction may be inspected monthly by PED, and, depending on their safety records, operating rigs may be inspected from four times per year to as infrequently as once every four years. The inspections are focused on any problem areas noted in the rig history. Cranes are inspected separately twice per year by independent inspectors.

Operational inspections by the PED focus on safety equipment and procedures, rather than on the structure of the rig. (Inspection of the latter is presumably left to the certification societies such as Lloyds or Det Norske Veritas.) Each rig must have on board a "Systems Manual" of standard safety practice as well an Emergency Procedures Manual. Inspectors check to be sure that rig staff members know the manuals and are aware of their responsibilities under them. A senior DOE official with whom we spoke could see little possibility of using data from several rigs to guide the inspection of any particular one; that is, it was not apparent to him how one might use aggregated component failure data, for example, to guide rig inspections.

Finally, as one final control on the safety of offshore operations, the DOE has the right to approve the operator's Offshore Installation Manager, who is responsible for the overall operation of the rig.

3.3.3 Other Actors in Offshore Safety Management in the U.K.

Operating and contracting companies that are active in the U.K. continental shelf area are organized into the U.K. Offshore Operators Association (UKOOA), which speaks for the industry on regulatory matters. Another important private body in the U.K. is the Oil Industry International Exploration and Production (E&P) Forum, which is an international organization made up of oil companies and petroleum industry organizations. The E&P Forum is concerned with all aspects of the exploration and production of oil and gas, and it puts particular emphasis on the safety of personnel and protection of the environment. It establishes industry positions on such matters, and represents its members' interests before the Internationl Maritime Organization, other U.N. bodies, and other governmental bodies and agencies. Since the E&P Forum's headquarters are in London, it seems to have particular saliency for the U.K.

Labor unions are heavily involved in representing the interests of offshore workers in the U.K., of whom approximately forty percent are represented by organized labor. The unions are more active in the U.K. than in the U.S., though not as active as in Norway. In 1974, six unions representing offshore workers in a variety of trades established the Interunion Offshore Oil Committee. This Committee has been offically recognized as the spokesman for organized offshore labor by the government and by the UKOOA, an industry group. The Committee has helped to reduce the barriers between the tradtional crafts to provide more flexibility of worker assignments in the non-traditional offshore workplace. The Committee and the UKOOA meet perhaps four times per year to discuss issues of mutual interest. The unions have an access agreement with the operators which allows union personnel to visit the offshore installations at the convenience of the operators. The unions also meet twice a year with the Department of Energy authorities to discuss issues of concern.

One approach to safety management used by some operating companies is to offer bonuses to groups of workers that achieve safe work records. Some union leaders in the U.K. are concerned that the adoption of safety bonus programs in companies tends to discourage the reporting of accidents that would jeopardize the bonus.

At the current time, neither the trade unions nor individual workers are involved in performing or analyzing the safety analyses of installations done by or on behalf of the operators or the government. In fact, it is difficult for workers to have an independent say in safety matters offshore. For example, the only way for a worker to contact someone on shore if he is concerned about a safety hazard and finds the operator unresponsive to his concern is to use the installation's radio telephone, which is controlled by the operator. It should also be noted that labor was not pleased by the Burgoyne compromise, and would prefer for worker protection to be administered in the offshore by the Health and Safety Executive (HSE). The HSE has formed an Oil Industry Advisory Committee with both industry and labor members to advise it on safety policy and to discuss problems about particular installations. It is said that the trade unions sometimes use this public forum to pressure the operators to modify a condition to which they object.

Certain universities and training institutes play important roles in managing the safety of offshore activities. Although not the only active university, Robert Gordon's Institute of Technology in Aberdeen, Scotland, is prominent in the field, with degree programs, training courses, and research studies in the area of offshore engineering and safety. For example, the university does nearly all survival training of offshore workers in the U.K. It offers a one-year, post-baccalaurate degree program in offshore engineering to train engineers for the offshore industry, and it offers a variety of other specialized training activities. In the U.K., apprenticeship programs are an important mechanism for training skilled workers for industry, and the only operator in the U.K. that offers such a program for offshore workers is British Petroleum.

3.3.4 Offshore Safety Data Collection in the U.K.

Safety-related data for offshore activities are collected in the U.K. by both industry and the government. Data regarding individual accident events, injuries and deaths are collected on a routine basis by the Department of Energy. Operators are required to report to the DOE on all serious and fatal accidents, and investigations are made of the more serious ones at the discretion of DOE. We assume that each operator and other offshore company also keeps data on accidents.

In addition to historical data on accident events, good safety management and analysis practice requires data on the performance and reliability of individual components of equipment and structures. The principal public source for such data in the U.K. is the Systems Reliability Service of the U.K. Atomic Energy Authority. However, they have only limited data of use to offshore installations, since they have an obvious bias toward components and devices used in the nuclear industry. Some of the U.K. operators are participants in the Norwegian OREDA project (see section 3.2.4.3), which is intended to gather and publish component reliability data from operating companies on an aggregated and confidential basis. Safety analyses done in the U.K. are heavily dependent on data collected for the U.S. Gulf Coast and on data available to the U.K. operators through contracts for analyses with engineering and consulting firms that have access to data from other North Sea countries, especially Norway. This study did not determine the extent to which such industry associations as the UKOOA collect or analyze safety-related data for the offshore.

3.3.5 Offshore Risk Analysis in the U.K.

The U.K. presents a mixed picture regarding the place and use of formal safety analysis for offshore activities. On the one hand, the British chemical firm, ICI, pioneered in the systematic application of formal risk analysis to hazardous industrial operations following an explosion at its Flixborough plant some years ago. Several U.K. engineering and consulting firms have developed substantial capabilities in formal safety analysis, in part as a consequence of the work at ICI. ICI staff invented the technique of "hazard and operability studies" (HAZOP) which is used to make systematic assessments of the risks associated with process systems, especially those elements intended to prevent mishaps from growing into damaging accidents. (see chapter 2 for details on the HAZOP method) Formal risk analyses have also been done for some large scale on-shore installations and for certain port developments, giving further credibility to safety analysis in the country. As discussed below, some operators and the government have also carried out or funded safety studies of particular installations or of certain policy decisions to be made regarding offshore development.

On the other hand, formal safety analysis plays a less systematic and more ad hoc role than it does in Norway. There are no formal requirements that operators do safety studies before building or operating offshore installations. There has been no systematic program of risk analysis research as has occurred in Norway's Safety Offshore program. Thus, while the U.K. has considerable capability to do safety analysis, it does not appear to have been considered as an essential part of offshore planning.

Despite the similar cultural and political bases for the U.S. and U.K. societies, there are some important legal and constitutional differences that account for the lesser role of analysis in decisionmaking in the U.K. government. Perhaps most important is our tradition that administrative rule-making decisions must be based on a formal record and that public officials can be called upon by the courts or the legislature, as well as by the citizenry in some cases, to show how they arrived at decisions they made and to display the data they used. This tradition of accountability in American government tends to compel us to make ever greater use of whatever tools of analysis are available.

Government officals in the U.K. make decisions in a much less public way, and they are not required to base their decisions on analysis. Hence the U.K. government, especially the offshore regulatory authorities, have not made use of the risk analysis capabilities available to them. Finally, in the U.K., studies that are done related to policy decisions or decisions about particular facilities are not required to be made public as in the U.S., and, in fact, it is usually forbidden to release them. Thus, our assessments of such work in the U.K. are based on indirect evidence and on conversations with their sponsors and performers.

The regulatory staffs of the Department of Energy and of the Health and Safety Executive in the U.K. are quite small. They have neither the time nor the skills needed to implement full-scale performance or review of formal safety studies.

In the government agency most concerned, the DOE and its Petroleum Engineering Directorate, formal risk analysis is currently within the province of the Research and Development Branch, rather than in a branch directly concerned with regulation. While there is apparently close coordination of the R&D and operational branches, it is not clear to what extent the regulatory programs have been affected by the analyses supported by the R&D group. The R&D branch has been more interested in pilot studies and in detailed risk analyses of particular technologies and operations than in comprehensive risk studies of entire platforms.

The Petroleum Engineering Division of the Department of Energy, through its R&D Program, has supported several experimental studies using risk analysis to assess its utility in the government's programs and to help answer certain policy questions. One such study, by Cremer and Warner Consulting Engineers, was a pilot study of the application of fault and event trees to an offshore production platform. Another, by Plessy Engineers, was intended to assess the usefulness of currently available data for doing offshore safety studies. Still another, by Reliability Consultants, analyzed the causes of diving accidents, while another study by the same firm is intended to analyze platform emergency evacuation procedures. The first two of these studies, for which we had access to formal reports, are discussed in chapter 4, while we can say nothing about the details of the other two.

Recently, the U.K. DOE sponsored a risk assessment of platform emergency evaculation which focused on the safety of totally-enclosed, motor-propelled survival craft. It has been reported that this study has stimulated a number of projects in the U.K. to improve evacuation systems. (McBarnet, 1983)

Formal safety analyses have been performed by U.K. offshore operating firms in connection with several major new installations, including the Morecambe Bay project of British Gas and a major private offshore oil production platform.

The Morecambe Bay project is a group of very large platforms intended to recover and process natural gas from Morecombe Bay on the West Coast of England. As part of the design process for the platforms, a concept engineering audit was done to help identify safety-related problems with the design, and a HAZOPS study was done of the process equipment plans.

For the new oil production platform, an overall safety study was first done using checklists to identify the ten most important areas of safety concern. Subsequently, more than twenty detailed studies were done of specific subsystems using the failure modes and effects analysis method to identify safety problems. Several hundred recommendations were made for design modifications following the detailed studies.

As one approach to determining the utility of risk analysis in offshore design and operations, the E&P Forum in London has been doing a study of its members' use of formal risk and safety analysis. The E&P Forum has also funded a simulation study of collisions of ships with offshore installations that was done by a private consulting firm in the U.K.

3.3.6 Offshore Safety-Related R&D by the U.K. Government

The U.K. DOE supports R&D related to the offshore industries through both the PED, which is concerned with safety-related R&D, and through the Offshore Supplies Office, which is concerned with offshore technology development more generally. The latter offers 50% support for development of new offshore technology, with the expectation of repayment of the government's share for successful projects. Here we focus on the activities of the DOE PED in R&D.

Annually, the PED supports approximately 3.5 million pounds Sterling of R&D activities, which is equivalent to about $4.5 million at current rates of exchange. A number of the offshore operators participate in so-called "ticket projects" with DOE, and industrial cost sharing on PED projects adds about 50% to this total. PED spends about one hundred thousand pounds of its R&D budget on risk analysis studies.

The R&D supported by PED is related rather directly to the regulatory objectives of the agency, rather than to the support of offshore science and technology in general. Most of the R&D funds are spent on structures in such areas as non-destructive testing methods, metal fatigue, and tension leg platform pilings. Whenever possible, PED tries to work closely with industry in designing, funding and carrying out its R&D program. Since DOE has no laboratories of its own, the actual research is done elsewhere. For example, the government's Building Research Establishment has a contract for about six hundred thousand pounds to do DOE's research on tension leg pilings.

The DOE PED is a participant in the project known as INFOIL II, which is an international data base of ongoing research projects in the offshore field. This data base includes projects that have not yet been completed so as to give other researchers the most current possible data on what is going on in the field. Another source of current awareness of offshore R&D in the U.K. is the bimonthly "Offshore Research Notes" published by the Engineering Group of the Construction Industry Research and Information Association. The PED's own reports of ongoing and completed research projects are apparently not generally available, since we could not have direct access to them while in the U.K.

3.4 SOME OBSERVATIONS ON OFFSHORE SAFETY MANAGEMENT IN NORWAY AND THE U.K.

Risk analysis plays a major role in the management of offshore oil and gas activities in Norway. The Norwegians have developed a unique system for management of their offshore oil and gas activities which strongly reflects their societal characteristics and would not be expected, therefore, to transfer easily to other contries. In particular, the Norwegian regulatory system is relatively non-adversarial, and is based on developing a consensus among the government, the parties being regulated, and the public. Thus, the highly developed use of risk analysis for managing the hazards associated with offshore oil and gas operations in Norway can be viewed as a tool for providing the basis for developing this consensus.

Although not explicitly required by regulation, risk analysis provides the method by which a licensee can show that the major hazards, their consequences, and possible methods for mitigating them have been consideed from the early concept evaluation stage of the project through to the construction of the facilities. Primary concern is directed to worker safety, with less emphasis placed on protection of the resource and the environment. However, all parties in Norway are well cognizant of the major role that petroleum plays in the economic well-being of the country, so that avoiding disruption of production is a high priority. Notwithstanding the strong concern for worker safety, the users of formal risk analysis techniques are more oriented toward identifying risks associated with large-scale catastrophic events rather than routine workplace accidents.

Intimately connected to the use of risk analysis in Norway is the system of internal control, in which the responsiblity for maintaining quality control and the safety of the operations is completely held by the operator. Since the Norwegian Petroleum Directorate monitors the operator's internal control system, rather than the operator's activities, fewer government personnel are required than if the operations themselves were monitored. In addition, by not specifying the details of the operations, the Norwegians believe they are encouraging innovation and the development and use of new technologies.

The research and development programs concerned with offshore safety jointly funded by the Norwegian government and the oil industry for more than $20 million and extending over five years have strongly influenced offshore oil and gas operations in Norway. The high level of effort also provides ample evidence of just how strong the concern for safety offshore is in Norway.

There is a great deal of interest and a fair amount of activity related to formal risk analysis for offshore activities in the United Kingdom. Such studies have not been mandated by the government or the certifying authorities, although the government has experimented with their use.

There appears to be more such activity among the operating companies and in the government related to process safety than to rig safety or structural integrity. It is felt by some that systems safety studies are more relevant to the design and construction phases and to major modifications of existing rigs than to the more routine area of operational safety. There is still felt to be a need for traditional personnel safety activities despite the use of formal systems safety studies and methods. The two are seen as complements, not substitutes.

In the U.K. offshore industry, safety analyses are done by subcontractors and consultants, not by the operating firms or their prime contractors. Even the large operators have only one or two staff members skilled in safety analysis to serve as their interface with consultants. Typically, a concept system safety study for a platform costs approximately $100,000, while a complete safety analysis of a detailed platform design may cost several million dollars.

For the most part, the operators have focused their safety analysis activities on the process parts of offshore installations, while the certification societies are more concerned with structural analysis. Methods such as HAZOPS that are tailored for process system safety studies generally require participation by the operator's technical and operational personnel if they are to take realistic account of the kinds of circumstances that can compromise platform safety.

Two kinds of concerns have been raised about the utility of offshore safety studies in the U.K. and Norway. One is that the studies are done by consultants and contractors who have little or no experience offshore and who thus have little basis for imagining the kinds of failures that can occur. This problem is further aggravated by the fact that very large platforms of the type being built in the North Sea are designed, built, installed and operated by complex associations of many different firms. This tends to diffuse the responsbility for safety and can lead any one of the participants to make design and construction decisions that ignore safety concerns raised by other participants in the process. The operators, who bear the ultimate responsibility for safety, do not have the staff skills and resources needed to keep track of all of the details of system design and construction.

A closely related problem is that the actual implementation and operation of an offshore installation is always different from how it is conceived in the original design, and it tends to evolve toward greater difference over time. This design evolution compromises the validity of the design safety analysis, and can lead to situations that are less safe than expected. It is not uncommon for persons with offshore experience to tell stories of how platform structural elements are modified, or even removed, to accomodate removal of equipment for maintenance or to facilitate access to the platform[5]. Such modifications of a design can inadvertently and dramatically increase the possibility of coincident or "common mode" failures on an installation, by introducing weak points in more than one safety system simultaneously.

Clearly, these problems are not inherent in the practice of systematic safety analysis. Instead, they are more properly seen as limitations on its utility for managing safety offshore on a routine basis, and indicate that other safety management practices such as routine audits, periodic recertification, giving opportunities to workers to point out safety hazards, and the like remain important.

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[5] A field modification apparently played a role in the catastrophic loss of the Alexander Kielland hotel platform. (Norwegian Ministry of Local Government and Labor, undated)

While the use of systematic safety analysis methods is intended to make offshore activities safer, it is not pre-ordained that this should be the outcome. For example, if an installation were grossly overdesigned in the absence of systematic safety analysis, and were less overdesigned following an analysis that made it possible to adopt a less conservative design, the installation could be less safe than before. Of course, the redesigned rig would presumably cost less, but those concerned with safety should keep their eyes open for this kind of perverse result of the application of formal safety analysis.

CHAPTER 4

A REVIEW OF SELECTED STUDIES OF OFFSHORE RISK ANALYSIS AND RISK MANAGEMENT

4.1 INTRODUCTION

The past decade has witnessed a rapid growth in the use of formal methods of risk and reliability analysis in the management of safety, health and environmental risks arising from offshore energy operations. This chapter is based on a review and analysis of selected reports of such applications in the U.S. and abroad.

The list of applications of risk analysis offshore is already too long to allow for a review of all of them. In addition, many of the most significant studies are not available for public review, because they were performed for private industry or, in the case of foreign countries, they are not made available to the public even when performed by or for governmental authorities. On the other hand, in certain technical areas such as reliability analysis, the scope of the published literature has already grown too large to allow for complete review here, and we discuss only selected studies.

In addition to studies that are easily identified as applications of formal risk analysis methods, we also review here selected major policy studies of offshore safety issues in order to illustrate whether and how such studies, most of which are well-known, have used formal risk analysis techniques.

This chapter critically reviews these studies of offshore related risks in order to illustrate some of the opportunities and difficulties of studying offshore risks, and to draw from the studies some lessons that may be of interest to the Minerals Management Service as it contemplates how it might make use of risk analysis in its own work, or encourage the use of such methods in industry. The studies were identified by a formal search of the literature, by conversations with knowledgeable professionals in the field in the U.S., and through our conversations with officials in Norway and the U.K. during our interviews there.

4.2 COMPREHENSIVE POLICY STUDIES OF OFFSHORE RISK MANAGEMENT

The first major category of studies includes major policy studies of risk management in the offshore industries done by official bodies and individual experts in the U.S. and Europe. These studies were all intended to give a broad overview of offshore risks in order to identify potential needs for research and/or regulations. Because they were concerned with the overall topic of risk management, which includes risk analysis as one of several possible components, all of these reports are concerned with more than risk analysis alone. Furthermore, each of them is relatively comprehensive in terms of the range of risk management issues it addresses. Each has been reported in full in the public domain and is available in written form. They are presented here in reverse chronological order.

Safety and Offshore Oil, Committee on Assessment of Safety of OCS Activities, Marine Board, Assembly of Engineering, U.S. National Research Council, 330 pp., 1981.

The Marine Board of the National Research Council has served for many years in an advisory capacity to the USGS and the MMS on policy issues and technical problems related to offshore safety management. This report was prepared by the Marine Board for the USGS to fulfill a requirement under the OCS Lands Act Amendments of 1978. The Marine Board reviewed existing regulations and technologies and assessed their adequacy in providing for personnel and environmental safety in OCS drilling and production. In addition, the committee was asked to develop a methodology for doing future studies of this kind. The committee did not use formal risk analysis methods, although it recognized that many different methods can contribute to assessing the role of technology and regulations in safety. Instead, the committee:

1. requested information and opinions on OCS safety from interested parties,

2. reviewed the historical record of safety of OCS activities, including previous studies,

3. assembled a data base on OCS technologies and regulations, and described social and technical perspectives that must be considered in an assessment of OCS safety,

4. generated an extensive set of questions on the adequacy of data, technology, and regulations to provide for the safety of OCS activities, and

5. held workshops at which the committee divided into teams to discuss the questions with invited experts in such areas as workplace safety, fires and explosions, loss of installations, well control, operational discharges, and spill containment and cleanup. Afterwards, the committee prepared its final report, which was independently reviewed before release.

The committee's approach is responsible for both the strengths and weaknesses of the study. On the one hand, the committee accomplished most of what it set out to do. It reviewed and assessed the safety of OCS operations, and made a large number of concrete recommendations. It also developed a list of questions that may help regulators assess technologies and regulations in the future. The approach did not divert the committee into spending excessive time on the analysis. By relying on the knowledge and opinions of experts and on inferences that could be derived from available data, the committee was able to achieve its goals effectively.

On the other hand, because much of the report is based on the experience of the experts on the committee, the make-up of the committee heavily influenced the results of the report. For example, the committee included representatives of industry and environmental groups but not of offshore workers or their labor unions. Thus it is not surprising that the committee concluded that "current technology and engineering systems now in use on the OCS appear to provide adequate workplace safety". By contrast, labor union representatives testified shortly after the report appeared that federal actions to assure workplace safety in offshore activities are inadequate. (Anon., 1982)

The Marine Board uncovered little new information. The methodology the committee used was incapable of identifying risks that were not already known to the committee members or their consultants and correspondents. In particular, the study did little to identify sources of risk to be expected in future operations. Since the committee did not systematically analyze offshore risks, there is no assurance that their analysis is complete. The committee analyzed and made recommendations on numerous problems that seem important, but used no formal procedure to ensure that all important problems were considered.

Offshore Safety, ("Burgoyne Report") Report of the Committee, Dr. J.H. Burgoyne, Chairman. Her Majesty's Stationery Office (U.K.), 300 pp., 1980.

This is the report of a committee set up by the Secretary of State for Energy in the U.K., "To consider so far as they are concerned with safety, the nature, coverage and effectiveness of the Department of Energy's regulations governing the exploration, development and production of oil and gas and their administration and enforcement." The committee was appointed to help resolve a dispute regarding whether the Department of Energy or the Health and Safety Executive of the U.K. should have primary responsibility for administering the provisions of the Health and Safety at Work Act in connection with offshore activities. (See chapter 3 of this report for further information on the context of the Burgoyne committee.)

In addition to the chairman, the committee was composed of seven members chosen from academia; trade unions; and consulting, inspection, and research firms. The committee was assisted by one technical consultant. It met weekly for forty weeks during its deliberations.

The committee invited testimony and evidence from interested parties, and visited a number of field sites. It performed no systematic risk analysis, but examined U.K. accident statistics and heard testimony from expert witnesses. The level of detail of the inquiry, as suggested by the recommendations the committee produced, is similar to that of the Marine Board study for the USGS. Its final report suggested regulations and technologies needed to enhance offshore safety. The committee offered a number of specific recommendations for action by the Government, and concluded that the Department of Energy could effectively enforce workplace safety standards offshore: a conclusion that was formally disagreed with by the labor union representatives on the panel.

The strengths and weaknesses of this report are similar to those of the Marine Board of the National Research Council, since both used available data and a panel of experts to assess and make recommendations concerning regulations and technologies for offshore safety. Comparing the results of the two studies highlights how different committee members, different accident statistics, and different regulations can produce different results. Although technologies and environmental conditions in the North Sea and in U.S. frontier areas are similar, the recommendations the committees produced for R&D are quite different. The Burgoyne report puts more emphasis on risks to workers and less on risks to the environment. As noted in chapter 3, this difference in emphasis reflects the different geographic circumstances of existing offshore developments in the two regions of the world. However, it also shows that the study done for the U.S. did not emphasize the changing nature of risks as U.S. development moves from the Gulf of Mexico to the North Atlantic and Alaska.

<u>Risk Assessment: A Study of Risk Levels Within Norwegian Offshore Petroleum Activities</u>, Safety Offshore, the Royal Norwegian Council for Scientific and Industrial Research. 203 pp., 1979.

This is the report of a preliminary project of the Safety Offshore Program. The report was intended to identify research areas and resources needed for the main project. The main project was to perform a total offshore risk analysis and to map out ways to reduce risks. The main project report was published in 1984 under the title, <u>Safety Offshore</u>, authored by Olav Kaarstad and Egil Wulff. (See chapter 3 for details of the Safety Offshore project and its place in the Norwegian offshore scene.)

The preliminary project participants came from several Norwegian institutes and agencies. Over a third came from Det Norske Veritas, a large consulting firm and certifying authority in Norway. Others came from the Norwegian Ship Research Institute, Scandpower A/S, The Norwegian Institute for Atomic Energy, Offshore Technology Testing and Research, The Foundation of Scientific and Industrial Research, and The Norwegian Institute of Technology.

In performing their analysis, the group described and modelled offshore operations, and collected data and statistics on operations, populations, and accident statistics for various aspects of offshore operations. They also performed a type of systematic risk analysis, in which they examined offshore systems, studied the probabilities and consequences of failures in them, rated the potential failures on a combined severity-probability scale, and listed research or measures needed to reduce the risks.

Because the purpose of the study was to identify areas for further research, the risk analysis was not performed in great detail. The descriptions of risks and measures to reduce risks are less specific than those of the Marine Board report for MMS, generally pointing to broad research needs such as "improve knowledge about helicopter crashes".

The study illustrates the benefits of using a systematic approach to the analysis of risks and of measures to reduce them. Because it is more systematic, it seems more complete than the Marine Board study, and it identifies some potential hazards that have not occurred and for which there is therefore no empirical data. It is not detailed enough to isolate specific risks to be encountered in frontier areas, but provides some indication of what the likely risks are.

The final report of the program, entitled Safety Offshore (Kaarstad and Wulff, 1984), is a brief but substantive summary of the activities of the 5-year safety offshore program. It discusses in summary form the results of a number of individual risk analysis projects done under the auspices of the program, some of which are reviewed later in this chapter. The report also contains a number of specific recommendations for areas in which additional safety-related research should be undertaken by the Norwegian authorities, and it contains explicit recognition of the fact that industry has a responsibility to carry out some of this research, including pointing out specific topics that should be pursued by industry. (A list of all of the projects supported by the Safety Offshore Program is published under the title, Safety Offshore: Outline of Reports (Royal Norwegian Council, 1973).)

Energy Under the Oceans: A Technology Assessment of Outer Continental Shelf Oil and Gas Operations, Don E. Kash, Irvin L. White, et al., The University of Oklahoma, 378 pp., 1973.

This is the report of a comprehensive study of offshore technologies, companies, and regulatory mechanisms supported by the U.S. National Science Foundation under the rubric of technology assessment. The study did not include a formal risk analysis. However, the study was performed at a time when environmental safety of offshore activities was of major concern, and it deals at length with these risks, the capability of the technology, the character of the industry, and the structure of the U.S. regulatory system.

The University of Oklahoma research group that conducted the study systematically considered the physical technologies and social technologies (for example, rules and regulations) for exploration, drilling, and production, as well as for shipping and transporting oil. They considered both current and future technologies and their primary and secondary impacts. In contrast to many technology assessments performed at the time, this study focused heavily on policy issues, and it considered specific options and their consequences, and made recommendations for action.

This comprehensive study of offshore operations provided considerable insight into the shortcomings and needed improvements in the management of risks accompanying offshore activities. Some observors trace the 1978 Amendments to the OCS Lands Act to the influence of the ideas in this report. Ten years later, the book is still remarkably current in this fast changing area, and it remains one of the best overviews of offshore activities.

North Sea Oil and Gas: Implications for Future United States Development, study sponsored by the U.S. Council on Environmental Quality, Irvin L. White, Don E. Kash, Michael A. Chartock, Michael D. Devine, and R. Leon Leonard, University of Oklahoma, 176 pp., 1973.

This study, which is built upon the foundation of the earlier study, Energy Under the Oceans, by the same authors and reviewed just above, was intended to "...compare the development of continental shelf oil and gas resources in the North Sea with U.S. development, primarily in the Gulf of Mexico. The results of this comparison become the basis for suggesting questions that should be raised and several possible beneficial changes that should be made in advance of developing East Coast and Gulf of Alaskan resources."

The study team depended heavily on a series of interviews carried out in the summer of 1973 with officials in the U.K., Norway and the Netherlands. The report contains nothing that could be described as a formal risk analysis, and is largely descriptive. It describes the regulatory institutions and procedures of the various countries, the nature of North Sea oil developments and technologies at that time, and the coastal and enviromental, but not the personnel safety impacts, of those activities. The report offers several recommendations for improving the management of U.S. offshore development based on the European experience.

4.3 LIMITED POLICY STUDIES OF OFFSHORE RISK MANAGEMENT

This group of policy studies of offshore risk management differs from the group discussed above principally in terms of the scope of issues with which it is concerned. Like the previous group, these studies are concerned with more than risk analysis, but none of them pretends to be comprehensive. Instead, they discuss particular problem areas or opportunities in the offshore arena, and some of them make use of, or allude to the use of formal risk analysis.

Safety Information and Management on the Outer Continental Shelf, Committee on Outer Continental Shelf Safety Information and Analysis, Marine Board, National Research Council, 112 pp., 1984.

This report, another in the series of Marine Board reports for the MMS, is in response to a request for, "an analysis of OCS safety information systems, including the types of information to be collected, analytical processes for utilizing data, and techniques for maximizing compatibility with other information systems." Like other NRC reports, it was carried out by a committee of experts, assisted by consultants, expert witnesses, and NRC staff.

The committee did not attempt to perform any formal risk analysis work, nor does its report refer at any point explicitly to the performance of formal risk analysis by either industry or government. Instead, the committee looked in depth at the collection, analysis and dissemination of data related to accident events, and to component reliability. In no instance, however, did the committee refer to the possiblity that such data might be useful for risk analysis activities, or that the design of data collection and dissemination systems might be carried out reflecting the needs of those who do risk analysis. The only exception to this observation is mention in passing of reliability analysis of safety equipment, but this is not explored beyond mere mention. The report does not refer to any of the literature on the subject of risk analysis, whether applied offshore or elsewhere. The committee does offer a number of recommendations for the collection, analysis, dissemination and management of safety-related data by the MMS.

<u>Safety Management in Offshore Development Projects: Description of a Project Model for Safety Management</u>, Bjarne Hope and Per A. Johannessen, Tanum-Norli, Oslo, 142 pp., 1983.

<u>Risk Analysis in Offshore Development Projects</u>, R.S. Andersen, et al., SINTEF (The Foundation of Scientific and Industrial Research at the Norwegian Institute of Technology, Trondheim) 107 pp., 1983.

The first citation is a report of a project carried out by Hope and Johannessen, along with a number of project participants, at the Norwegian consulting firm, Bedriftsradgivning, a.g. The project was supported by the SPS (Safety Offshore) Program of the Norwegian government. (see chapter 3) The purpose of the project was to develop and document a systems model for the planning and operation of a major offshore installation that would incorporate the best available approaches to the management of risks to workers, the enviroment and property.

The second citation is report of companion project to describe how and when different risk and safety analyses should be carried out to perform the kinds of studies call for in the first citation.

The systems model presented in "Safety Management" includes as many as ten separate points at which safety analyses might be appropriate, and these analyses could be of five distinct types, including rough risk estimates, concept analyses, hazard analyses, overall risk analyses, and risk analysis of construction work. These analyses would be performed at various stages of the design of a project, from feasibility studies to detailed engineering. The report emphasizes the importance of doing such studies as early as possible in the design process so that accomodations to safety needs can be made with the least expensive impact on the design. The report acknowledges that ten separate analyses may seem to be too many, but argues that this is necessary to achieve a field concept or platform design that satisfies the safety objectives. The report offers several highly detailed flow models of a design process and of the roles of safety analysis and documentation at each stage. It is written and displayed in the language of systems analysis, which lends to it an aura of complexity that may reduce its credibility in the eyes of some potential users, especially in view of the large number of studies for which it calls. It should be noted that this study is viewed as an idealized model by the offshore regulatory authorities in Norway and is not contemplated by them as the basis for a requirment for an adequate safety analysis.

"Risk Analysis" by the SINTEF team provides much more detail on the appropriate analyses to be done for each of the safety studies in the Bedriftsradgivning framework. While it is not a primer on risk analysis techniques, this report offers many insights into when each type of analysis (discussed in chapter 2 of the present report) should be done. It also offers guidance into the key assumptions that must be made, and it ties these to Norwegian regulatory requirements. It contains an extensive bibliography of references to the primary risk analysis literature.

Managing Technological Accidents: Two Blowouts in the North Sea, David W. Fischer, ed., Pergamon Press, 234 pp., 1982.

This book, which is based on a workshop held at the International Institute of Applied Systems Analysis in April 1978, reports analyses of disaster response to two major North Sea blowouts, at the Bravo Platform in the Norwegian Ekofisk field and at the Maersk Explorer Platform in the Danish North Sea. It includes papers describing the blowouts and responses to them by the authorities and by the industries in the two countries. It includes a paper by Fischer in which he compares the Ekofisk blowout to the Three Mile Island nuclear power plant incident in the U.S. and finds striking parallels between them.

The book includes papers by several prominent Norwegian analysts that describe the application of risk analysis techniques to the problem of blowout prevention. These papers serve as an introduction to the field and provide a convenient illustration of the application of risk analysis, particularly fault and event tree methods, to offshore safety problems.

The Other Price of Britain's Oil, W.G. Carson, Rutgers University Press, 320 pp., 1982.

This book, the writing of which was supported by grants from the U.K. Social Science Research Council and the Scottish Home and Health Department, is an account by a sociologist and social critic of the impact of the development of offshore energy resources in the U.K. on worker safety. It includes a detailed analysis of how the economic pressure to produce oil quickly in the British North Sea led to a de-emphasis of measures to ensure worker safety. It also desribes in some detail the conflicts over offshore safety regulatory jurisdiction between the Department of Energy in the U.K. and the Health and Safety Executive, a topic which is the concern of the Burgoyne report discussed earlier in this chapter.

The book was written during the relatively early phases of large-scale development, and describes a situation which a number of observers in the U.K., including some representatives of the trade unions, believe has improved substantially in the interim. Carson was especially concerned with the high fatality rates in offshore operations, and as noted in the section of chapter 3 dealing with the U.K., these rates have declined with the shift of activity from exploration to development and production. On the other hand, the book is a useful antidote to those who either overemphasize the benefits of offshore energy production to a nation or focus only on the spectacular losses associated with major accidents, and fail to notice the cumulative undesirable consequences of major industrial activities in the areas in which they occur. Finally, it should be noted that the book makes no use of formal methods of risk analysis, nor does it refer to the results of such studies.

Health and Environmental Effects of Oil and Gas Technologies: Research Needs, R.D. Brown, Mitre Corporation, Metrek Division, 1981.

This study assesses research needs by reviewing the literature on offshore technologies and hazards to determine what needs to be done to develop safer technologies. No risk analysis was performed in the study -- it makes its recommendations for research and new practices based on the literature review. The level of detail of the study varies according to the literature in the field. The recommendations are about as detailed as those of the Norwegian study, Risk Assessment, cited above.

This study demonstrates that it is not necessary to do original risk analysis to gain useful insights into offshore risks. Much can be learned by a careful review of previous studies. This study identifies several risk-causing factors that did not appear in most of the other studies reviewed above. In particular, it notes the important influence of the offshore workers' environment on their performance. Literature surveys used alone, however, are limited. They do not create any fresh information, and are limited by the fact that not all of the important information is published.

4.4 EXPLORATORY STUDIES OF THE APPLICABILITY OF RISK ANALYSIS TO OFFSHORE ACTIVITIES

Application of Risk Analysis to Offshore Oil and Gas Operations - Proceedings of an International Workshop, U.S. Department of Commerce, National Bureau of Standards, NBS Special Publication 695, May 1985.

This workshop, held in March 1984 and sponsored by the National Bureau of Standards in cooperation with the MMS, was intended to examine how risk analysis might be used in offshore oil and gas operations. The workshop was intended to be for "educational purposes to define the current state-of-the-art; it is not the intent of the workshop to formulate MMS policies on risk assessment."

Approximately 75 experts from around the world in industry, government, universities, interest groups, and consulting firms gathered for two days to examine the applicability of risk analysis. A large portion of the effort was devoted to working groups that dealt with specific issues such as Standards, Codes and Certification; Concept Evaluation and Design; Operations and Maintenance; and Logistics and Support. In addition, the conference heard papers presented by a number of experts. The conference resulted in this report that includes the workshop papers and reports from the various workshops.

Costs and Benefits of USGS Outer Continental Shelf Regulations, Volume 3, Preliminary Risk Analysis of Outer Continental Shelf Activities, Arthur D. Little, Inc., 1982.

This report, done under the sponsorship of the MMS, included one element that was based on a formal analysis of risk. The purpose of this study was primarily to demonstrate the potential of the Arthur D. Little, Inc. (ADL) risk analysis methodology in assessing the effects of existing regulations on offshore risks. Although the risk analysis part of the study had a limited budget of about $45,000, the scope of the risk analysis was quite broad, including events leading to property damage, oil spills, injuries and fatalities in offshore oil and gas operations. The methodology used by ADL was to create logic diagrams or fault trees, and to quantify the logic diagrams from the top - down using accident statistics, rather than from the bottom - up using component failure rates. The ADL fault trees are more detailed than those used by Cremer and Warner in an exercise of similar scope. (See below) ADL staff responsible for the fault trees said they were made as detailed as the accident descriptions in the USGS Events File would permit.

The ADL methodology provides a clear graphical representation of the accident statistics that they used. While quantifying the fault trees with accident data rather than with component failure data is appropriate for their purposes, the method can only be used to quantify the probabilities and consequences of accidents that have already occurred. For example, their pre-1975 "loss of well control while drilling" fault tree shows the failure modes of 11 historical blowouts, but it does little to anticipate or predict other ways that blowouts could occur. While this approach was not used, it would have been possible to use expert judgment to develop and quantify branches of the fault trees on which accidents have not yet occurred.

The ADL fault trees are simplified, lacking in detail, and sometimes incorrect. (For a detailed critique of the ADL report, see Appendix II of the thesis by Cheney, 1983) The addition of several more levels of detail would greatly increase the contribution of the diagrams to the understanding of offshore risks. However, this could only have been accomplished through a substantially greater level of effort than ADL was able to expend. Most of these shortcomings are the result of a relatively small budget. However, if the results of an analysis are incomplete or uncertain due to limited resources, these limitations should be made clear. The complexity of fault trees requires that they be explained fully so that the client can understand the tree and the assumptions that underlie it, and not just the results.

A more fundamental criticism of the method used by ADL is that it must treat the state of each piece of equipment as if it is either working or not working. Similarly, environmental stress is treated as occurring or not occurring. In reality, however, the state of the equipment may range widely in the region between working and not working, and whether it works may be a continuous function of the amount of environmental stress. Logic diagrams for such circumstances can best be regarded as approximate descriptions of how systems fail, rather than as exact representations to be used to calculate failure probabilities.

<u>Risk Analysis Process in Offshore Development</u>, J. E. Vinnem, The University of Trondheim, The Norwegian Institute of Technology, 81 pp., 1982.

This report, prepared by one of the foremost authorities on risk analysis for offshore applications in Norway, is intended to serve as an introduction and overview of risk analysis for persons who may be the position of having to comply with the new guidelines for safety evaluation of platform conceptual designs of the Norwegian Petroleum Directorate. It also serves, however, as an introduction for anyone concerned with offshore risk analysis, as it is written in non-specialist language.

As its basis, the report breaks the process of risk analysis into five parts: system identification and description, identification of hazards, analysis of possible causal events of hazards, analysis of consequences, and estimation of risk as the product of probabilities and consequences. The report is specific to fixed offshore installations, for which the major types of undesirable consequences are fires and explosions, and techniques for analysis of these outcomes are described. The report is based on the assumption that a complete risk analysis will involve the quantification of the risks involved, at least in an order-of-magnitude sense. Finally, the report describes principles for defining the "design accidental events" required under the NPD guidelines, and describes the implementation of concept requirements into detailed engineering requirements.

A Preliminary Study into a Method for Hazard Determination and Risk Management in the Offshore Industry, B.D. Krause and G.R. Dodd, Plessey Assessment Services Limited, 23 pp., 1980.

This report of a study done for the Petroleum Engineering Division (PED) of the U.K. Department of Energy had as its objective, "to examine potential management systems by which the [PED's] funding might be allocated to the resolution of problem areas on a risk-related, auditable basis." The funding in question is that which the PED has available to spend on research and development projects intended to ensure that adequate safeguards exist in regard to the safety of personnel and equipment, the control of pollution, and the continuity of production. The project was quite limited in scope and involved the expenditure of only one man-month of effort by Plessy analysts.

The paper examines the risk management responsibilities of the PED, reviews briefly various methods of ranking risks, including risk analysis, and offers a proposal for a management system that would use information about risks to guide the R&D effort. While no attempt is made to actually carry out a formal risk analysis in this project, the management scheme envisions that a fault-tree analysis would be a part of the system, if implemented.

Analysis of Risk in Offshore Operations, (1980), and Methods of Presentation of Risk in Offshore Operations, (1981), Cremer and Warner Consulting Engineers, London.

These two documents report the results of a study for the U.K. Department of Energy that was intended to produce an overview of the factors affecting offshore safety and to identify where R&D is needed. They use cause-consequence analysis, a combination of fault-tree and event-tree analyses, to determine the relationships between failures of systems and risks to life, to the environment, and to the continuity of supply for exploration, development, production and transportation of offshore oil and gas. They excluded consideration of workplace injuries.

The study is preliminary in nature, and has several limitations, many of which are due to its limited budget. First, it does not go into sufficient detail to identify ways to reduce risks. For example, the Cremer and Warner fault tree for a "blowout while drilling" sheds little light on how to reduce the frequency of blowouts. While the study attempts to establish broad risk levels for different offshore operations, it is focused largely on production activities. The risk analyses are much more detailed for production than for exploration, and interruption of supply is treated as the only important economic factor, neglecting the great economic costs of the loss of a drilling rig. This focus may reflect the characteristic of the British oil operations (loss of supply may be deemed more important than loss of a rig because the U.K. government may lose revenue from loss of supply, while insurance firms lose revenue from rig loss; alternatively, production might be a much more important component of British sector activity than exploration), or it could be due to the areas of expertise of the conductors of the study.

The study does not carefully consider where the existing risk data comes from and what its limitations and uncertainties are. For example, much of Cremer and Warner's data on estimated failure frequencies, such as those for the collapse of a steel jacket platform, are cited as coming from Risk Assessment, the Royal Norwegian Council study discussed above. However, in Risk Assessment the data is cited as coming from a Det Norske Veritas report, which is based in turn on USGS Gulf Coast data. Thus, although the data is cited as coming from Norway, it is actually based on data from the Gulf Coast where the types of platforms and environmental hazards are much different.

Furthermore, the source of data heavily influences the results. For example, Cremer and Warner concluded that helicopter accidents account for 91% of the risk to personnel in the North Sea. However, the British sector of the North Sea had had only one of the 35 North Sea helicopter fatalities up to that time. If Cremer and Warner had used British rather than total North Sea helicopter accident statistics, helicopter accidents would have accounted for a much smaller percentage of fatalities. Had they used Gulf Coast statistics, the results would have been even more different.

While the Cremer and Warner reports accomplish a great deal considering their limited budgets, they are also illustrative of some of the pitfalls in using fault-tree/event-tree analysis. The results of such analysis are very dependent on the data used and on the expertise and biases of the people conducting them. Furthermore, because logic diagrams used in fault-tree and event-tree analyses are more difficult for most readers to understand than non-mathematical descriptions of risk, they can hide the uncertainties in the data and analysis.

Hazard Analysis of a Single Well Caisson; Hazard Analysis of a Multiple Well Satellite; Hazard Analysis of a Complex Oil Production Platform; Hazard Analysis of a Complex Gas Production Platform; Hazard Analysis of a Pipeline, General Electric Co., 1974, 1975. (USGS Reports HA-7 to HA-13)

These six studies done by GE for the USGS (a seventh companion study of the hazards of a mobile drilling platform has not been available to us) were intended to "demonstrate the usefulness of hazard analysis techniques in identifying those equipment, procedures, and situations in which a failure or failures could result in pollution, fires, explosions, or compromise personnel safety." The studies are qualitative but quite detailed. They consider the effects of failures of individual components on system safety, and rank the seriousness of these hazards.

These reports and the ones by Southwest Research Institute (Franz, et al., 1973) described below were carried out pursuant to the recommendations of a study of the use of systems safety analysis techniques done for USGS in 1971 by experts from the National Aeronautics and Space Administration (Dyer, et al., 1971) Subsequent to their completion, the USGS proposed in a Federal Register notice dated January 14, 1975, to develop an OCS order on Systems Design Analysis, along with a Geological Survey Standard setting forth the requirements for performing such analysis. (40 FR 2597, January 14, 1975.) On May 19, 1977, the USGS announced development of a proposed standard which detailed a method of performing a Systems Design Analysis on oil and gas facilities on the OCS. Such an analysis would have been required prior to the installation of production equipment on a new platform, and a full analysis would have been required in connection with any modification of existing process components. Industry opposition to the proposal was strong, and resulted in the development of API Standard RP 14C for the analysis of safety systems on fixed platforms offshore. (see below) In January 1979 the USGS withdrew its proposal for a required analysis.

The method General Electric used is more time consuming than logic diagram analyses, because it considers the failure of many components that are not critical to the safety of the system. It concentrates on equipment failure and places little priority on human error. Nevertheless, the studies provided useful information about which offshore systems deserve attention for reducing risks.

<u>Summary Final Report on Failure Mode and Effects and Hazard Analyses for Offshore Oil and Gas Installations</u>, C.R. Franz, M.D. Pish, and B.W. Vanzant, Southwest Research Institute, 1973.

This report is the companion to the report prepared for the USGS by General Electric discussed above. Since this is only the summary report of a much more extensive study (copies of which could not be located for us by MMS), it is difficult to comment on the substance of the work. It is included here only to note its availability. Based on hazard analyses and failure modes and effects analyses (FMEA) of six types of offshore installations, the study identified problem areas requiring further study and made recommendations about the uses of hazard analysis and FMEA.

4.5 APPLICATIONS OF RISK ANALYSIS TO SPECIFIC OFFSHORE ACTIVITIES

There already exists an extensive literature on the applications of formal methods of risk analysis to specific offshore activities. In this section of this report, then, we can review only a small fraction of this literature to give some sense of its scope and utility. Emphasis here is on studies that have had an importance either historically or to particular private and public decisions about offshore risk management.

The Application of Hazard and Operability Studies and Hazard Analysis to the Offshore Industry, H.G. Lawley, Proceedings of U.K. Offshore Safety Conference, Eastbourne, Sussex, U.K., 1982.

Lawley, a senior hazard analyst for Shell, U.K., and a former employee of ICI concerned with risk analysis, illustrates in this paper a Hazard and Operability Study (HAZOP) and a subsequent Hazard Analysis (HAZAN) using an offshore production platform as an example.

The HAZOP is a procedure for systematically checking the causes and consequences of deviations from normal of the states of the elements of a system. The elements are such parts as tanks, valves, pipelines, electical connections and the like, and the states are indicated by such parameters as temperature, flow rate and direction, polarity, pressure and the like. The method uses a series of guide worwds to facilitate identifying the deviations. For example, the guide word "none" causes the analyst to think of the possible causes and consequences of no flow or reverse flow through various parts of the system. The analyst identifies the causes and consequences of each deviation, and decides on necessary actions to be taken if the deviation occurs or to prevent the deviation if necessary. Typically, a HAZOP is performed by a team of persons who are expert in the details of the system under study as well as a person skilled in the HAZOP procedure.

Some of the deviations uncovered in a HAZOP may require further analysis, and for these a HAZAN is preferred. In this study, the HAZAN of systems involved estimating the probabilities of some deviations using fault-tree analysis, and assessing options that could be implemented to reduce the hazards to acceptable levels. In the example, the HAZOP found some unacceptable hazards, including the possibility of reverse flow due to a poorly designed check valve on the main oil line. Ways to reduce the hazards to acceptable levels were then designed.

The method used in the study seems very appropriate for identifying and correcting aspects of an offshore production system that could lead to system failure. The method is efficient, using a broad approach to identify problems and a detailed approach to assess and investigate them. In the example, the analysis led to discovery of faults that might not otherwise have been found until the system was operational and the faults more costly to fix.

Offshore Blowout Control, O. Mundheim, et al., OTTER (Offshore Technology Testing and Research Group) of Norway, 1981.

This study, sponsored by Statoil and performed by a consortium of Norwegian groups, assessed the risk of blowouts on the Norwegian continental shelf, examined technologies for reducing the risk, and estimated the costs and benefits of using the technologies to reduce the risk. They looked for statistical differences between the frequencey of blowouts in the Gulf of Mexico and the North Sea. They also assessed the consequences of different types of blowouts. Much of the study is devoted to ameliorative measures. The authors describe a number of current and future technologies that can intervene in the blowout sequence, by preventing kicks from becoming blowouts, by stopping blowouts, or by reducing the damage from them. They perform a cost-benefit analysis to establish priorities among the technologies.

The study has some limitations, and some notable omissions weaken it. First, they assume that the blowout sequence originates at a "kick," rather than in the circumstances that lead to a kick. (A kick is an unexpected penetration of low-density oil or gas into the bore hole that causes a sudden drop in the total pressure, or head, in the hole due to the column of drilling mud.) Thus, the analysis does not consider technologies that help prevent kicks in the first place. This is a major omission since several technologies, including downhole sensors and techniques for predicting downhole pressures, may be among the most cost-effective ways of reducing blowouts. For example, the Marine Board study of offshore safety (see above) gives these technologies high priority.

Second, the study considered only technological approaches to blowout control. The objective of the study was to evaluate concepts for well control including preventive strategies in which human factors and procedures play an important role. Blowouts result primarily from human error, and the incidence of such error can be influenced by the design of the interface of man and machine. By taking too narrow a scope, the study's results are less significant than they might have been.

By examining statistics on the rate of occurrence of blowouts rather than using logic diagrams to study their causes, the study obtained useful data on the occurrence of blowouts without getting bogged down in detailed analysis. On the other hand, by not analyzing the causes of blowouts, an overly limited view of possible measures to reduce them may have been adopted. This illustrates a trade-off in performing risk analyses: spending too much time using logic diagrams to analyze risks leaves too little time for determining ameliorative measures; while spending too little effort on analysis can limit one's insights into how to change the system.

Safety Analysis Aids System Design, A. Leroy, Oil and Gas Journal, March 3, 1980; Analyse du risque de perte du riser lors d'un forage par 1800 metres d'eau, A. Leroy, Petrole et Techniques, October 1981; Risk Assessment as Applied to a Complete Seabed Production System, A.M. Lyon, European Offshore Petroleum Conference and Exhibition, 1980.

These three papers represent a larger group of risk analyses that have been performed by or for offshore firms to evaluate specific new technologies. These papers have similar objectives, scopes, methods, and data, so it is convenient to discuss them together.

These studies analyze the safety of three untried technologies: a deep water riser, a deep sea production system, and a seabed production system. Each study is intended to estimate the safety or the reliability of the system, in order to compare it with alternative concepts or to identify ways to improve its reliability. Each used a fault tree or fault-tree/event-tree approach, using component failure rate data from general industrial experience, sometimes combined with expert judgment. "Analyse du risque de perte du riser" (Risk Analysis of Riser Failure) gathered expert opinion on failure rates using the Delphi method.

The papers are all based on more detailed reports, which are not publicly available. Each paper claims that the analysis found acceptable safety levels for the system analyzed. However, none of the studies explicitly states its estimates of the system reliability or of the uncertainties in the reliability estimates.

Because these papers are brief summaries of proprietary studies, it is difficult to judge their strengths and limitations. However, they do demonstrate that risk analyses of untried offshore technologies can and are being done. These studies of small systems require a substantial effort. For example, the riser risk analysis took ten engineer-months.

<u>Risk Analysis of a Typical North Sea Petroleum Production Platform</u>, Odd J. Tveit, Bjorn Myklatum, and Odd Vesterhaug, <u>Proceedings of the 1980 Offshore Technology Conference</u>, 1980.

This study analyzes the risks of a generic North Sea production platform with the purpose of gaining experience with and further developing risk analysis methods, improving knowledge of risks on North Sea production platforms, contributing to improved platform design, operation, and maintenance, and improving risk and safety communication with authorities. The study considers risks to life and the environment that occur on operating production platforms. It excludes the risks of construction and installation of platforms and the risks of transporting personnel to a platform.

To carry out the analysis, the platform was divided into "analysis blocks" in several ways: areas of the platforms, type of technology, and type of operation. These blocks were then grouped into five groups:

1. Platform areas with equipment containing high pressure gas or oil,

2. Platform areas containing large quantities of crude oil,

3. Platform areas that could have harmful effects on living quarters,

4. Well-drilling operations, and

5. Critical operations on the process equipment with special attention to operations on the well systems.

For each analysis block, the potential hazards; i.e., events that could result in or develop into a life- or pollution-threatening accident, were identified. For each hazard, both the probability and consequences were assessed. If statistical data on the frequency of the hazards were inadequate, fault-trees, quantified with component failure rates from general industry experience or from judgmental estimates were used. For other hazards, such as occupational accidents, the hazard rates could be estimated directly from available data. The consequences of each hazard were analyzed with event trees. Critical events were chosen so that the event-trees were longer than the fault trees. The results of the study were estimates of the risk-dominating hazards and platform areas, and assessments of the general hazard levels of the platform.

The analysis reported in the paper seems to be based on analyses of several specific platforms that have been aggregated into the analysis of a "typical" platform. Although the parent analyses were apparently detailed, the paper itself provides few details. The paper illustrates the capabilities of fault-tree/event-tree analysis when applied to a large system. A production platform is a large combination of systems, yet it is only a subset of all offshore operations. Although the cost of the analysis is not given, it appears to have been an extensive study, yet the estimated uncertainties of the results are plus or minus a factor of ten. Finally, the study does not consider the types of risks that the methodology would find difficult to treat -- risks resulting from continuous rather than discrete hazards, such as structural failures due to wind and wave loadings.

<u>Risk Analysis of Offshore Production and Drilling Platform</u>, S. Fjeld, T. Andersen, and B. Myklatun, <u>Proceedings of the 1978 Offshore Technology Conference</u>, 1978.

This study considers the risks to the crew on board a large integrated drilling, production, and living quarter platform to determine whether an integrated platform can be as safe as an installation that houses the crew separately from the drilling and production operations. The study considered risks from blowouts, fires, explosions, collisions, helicopter crashes, earthquakes, weather, structural collapse, and sabotage, and considered both the consequences of these risks and ways to reduce the harm to workers on the platform. The study did not use logic-diagram approaches, but used matrices and tables. The paper does not provide full details of the study, but suggests that the study was detailed. The analysis, which is based on accident statistics from the USGS, recommends design criteria for various parts of the platform to meet various hazards in order to reduce risks to workers. They claim to have developed general techniques for high level safety analysis that can be accomplished quickly and cheaply. The framework for structuring engineering judgment seems straightforward and efficient.

Recommended Practice for Analysis, Design, Installation and Testing of Basic Surface Safety Systems on Offshore Production Platforms, American Petroleum Institute, API RP 14C, Second Edition, January 1978.

This is a set of recommended practices for designing process and related systems for offshore applications. It is structured in terms of detailed flow diagrams and check lists for actions that should be taken to ensure that process systems pose only acceptable risks to personnel, the environment and the facility. Such lists and diagrams are presented for such components as wellheads, flowlines, vessels, fired components, pumps, compressors, pipelines and heat exchangers. The overall emphasis is on determining the kinds of safety equipment and devices that need to be installed to protect against hazardous events, rather than on designing different concepts and system organizations that might be able to avoid such events or ameliorate their consequences.

This document, which is basically a handbook for use by design and safety engineers, represents the product of a generic analysis that is similar in approach to a Hazard and Operability Study (HAZOP). However, rather than assuming that a separate HAZOP should be done for every installation, this approach assumes that such a study can be done generically and then, in most instances, be applicable to a variety of platforms.

One of the limitations of the approach taken here is that all hazards are treated as being roughly the same in importance, in the sense that no attempt is made to quantify either the frequency or the consequences of each hazard. Furthermore, each hazard is treated as if it were isolated one from all others, an approach that may lead analysts to overlook commom-mode failures that may be of major consequence. On the other hand, this approach does help to ensure that some kind of rigorous analysis of the hazards of each installation is carried out in a timely and cost-effective manner.

As noted earlier in this chapter, the issuance of this recommended practice was stimulated by a draft USGS proposal to promulgate an order requiring that systems safety studies by done for all new fixed installations and for old installations upon repair. While the approach adopted by API may have been adequate for the design of relatively routine and standardized platforms for the Gulf of Mexico, it remains to be seen whether such a handbook approach will prove adequate for the design and analysis of much larger and more complex installations in frontier areas.

4.6 OFFSHORE APPLICATIONS OF STRUCTURAL RELIABILITY ANALYSIS METHODS

Methods of Reliability Analysis for Jacket Platforms, M.J. Baker and T.A. Wyatt, paper presented at the Second International Conference on Behaviour of Offshore Structures, London, England, 1979.

Reliability Considerations in Offshore Platform Criteria, Robert G. Bea, Journal of the Structural Division, September 1980, pp.1836-1853.

Integrity of Offshore Structures, D. Faulkner, M.J. Cowling, and P.A. Frieze, eds.,1981. Englewood, NJ: Applied Science Publishers.

Reliability of Structural Systems, Fred Moses, paper presented at 1976 Conference on Behaviour of Offshore Structures, the Norwegian Institute of Technology.

The above titles are a sampling of an extensive literature on probabilistic reliability analysis and design of structures. Analyses of offshore structures differ in several ways from the other types of analysis considered here. Unlike many other offshore systems, which are made up of independent components, the components of offshore structures are highly interdependent. The failure of one part of a structure will change the stresses, and thus the failure rates, on the other parts of the structure. Second, the sources of failures are usually externally-applied stresses such as waves, wind, collisions, and earthquakes, which act on the whole structure simultaneously. As a result, logic diagrams which best model the relationships between independent components are poorly suited to assessing the reliability of structures. Also, weaknesses in the structure are difficult to detect, and the structures are difficult to modify or repair; unlike other offshore systems the components are not interchangeable. Thus the risk analyses must occur during the design stage, and the structures must be designed and built to last a long time. Furthermore, they must be designed to withstand fatigue.

Reliability analyses of offshore structures focus on the probability of external forces exceeding the design strength of the structure when there is uncertainty in both the occurrence of external forces and in the strengths of components of the structure. The results of analyses are incorporated into design procedures and are used to determine appropriate safety factors.

Different types of structures require different analysis techniques. For example, for large rigid structures the relationship between the natural frequencies of the structure and the expected frequency of waves becomes important. Similarly, analyses of compliant structures must consider the effects of cyclic loading of waves on the fatigue of different components of the structure. Because the analyses differ for different types of structures, it is difficult to generalize about these analyses.

4.7 OBSERVATIONS AND CONCLUSIONS

4.7.1 The Role of Workers in the Analysis of Offshore Risks

Most of the studies reviewed above have relied on analysts who have little or no daily contact with offshore risks. An alternative mode of analysis would be to use more directly the knowledge and experiences of those who are in daily contact with offshore risks; namely, the workers. After many offshore disasters, survivors come forth with stories of unsafe conditions, frequently followed by lawsuits. (Thurow and Mufson, 1982) For example, contrary to the assumptions of many analysts, the equipment on many facilities, some of it safety-related, is not necessarily in working order all of the time. Many people on the rig know about potentially hazardous conditions, both in terms of specific equipment on a given rig that needs to be fixed, and in terms of general conditions among many rigs that need treatment through R&D, regulations, or incentives. The captain of a supply boat will know a great deal about measures that can prevent boat/platform collisions, which an analyst studying statistics or an "expert" from an oil company or a government agency may not know. Similarly, a driller on an oil rig knows a great deal about dangers on the drill floor and how to prevent them.

Many of the underlying causes of accidents - poor morale, dirty workplaces, poor maintenance, and animosities between workers and supervisors - cannot easily be uncovered by formal analysis, but can be discovered by talking with workers on the rig. Methods of gathering and distilling their insights, such as surveying offshore workers or including them in workshops, might be explored in order to improve the quality of formal safety studies. The same is true, of course, for those on the rigs in supervisory or professional positions; in fact, the HAZOP procedure is designed specifically to tap into the expertise of operating supervisory personnel, if not yet into the expertise of the workers themselves.

4.7.2 The State of the Art of Offshore Risk Analysis

Experiences with the use of various types of risk analysis show that it can make an important contribution in addressing offshore safety and environmental risks. It has been used in setting regulatory priorities, in checking the detailed design of major offshore systems, and in a number of other functions in both the private and public sectors in Norway, the United Kingdom, France and the United States. The specific studies cited in this report are only a small portion of the literature on this subject.

On the other hand, it is also clear from the record that many important studies of offshore safety do not use formal risk analysis, or if they do they use only the simplest techniques and approaches. It is very unusual for anyone to do a complete risk analysis for an entire offshore system, as has been done, for example, in the case of nuclear power plants in the U.S. Instead, subsystems and components have been studied in detail, and particular aspects of operations such as evacuation boats and stand-by vessels have also been analyzed. An interesting exception is a study of a complete production facility said to have been sponsored by STATOIL in Norway. However, the details of this study have not been made public.

More work is needed to establish the utility of risk analysis for offshore activies, especially in frontier areas where there is little experience to use to validate the results of analysis. Validation is also hindered by the wide-spread practice of not publishing the details of existing studies done in industry and government. Unless these studies become available for scrutiny by experts in the field in universities, industry, consulting firms, environmental groups and others, it will be difficult to improve the state of the art of such analysis and it will be difficult to assure decision-makers and the public that risk analysis can make useful and positive contributions to more effective offshore safety management.

No uniformly right or wrong way of doing risk analysis is apparent from the studies. Each of the methods has its uses, and success in using risk analysis depends on a wise and creative use of the various methods, often two or more in combination.

Quantitative fault-trees seemed most appropriate when applied to relatively small systems, as in the studies by Leroy (1980, 1981, 1982) and by Lyon (1980), but for larger systems seem only useful in a descriptive sense or to structure an analysis. For very large systems such as complete offshore platforms or entire processing systems, fault-trees simply become too large to handle. Some progress in doing very large fault-tree studies has been made by implementing them in a computer code. For typical large system studies, a more useful approach may be to do a number of nested studies, with the specific methodology and the level of detail differing for different system levels and different system functions. A study strategy of this sort developed to meet the requirements of the Norwegian regulatory system is described in this chapter. (Hope and Johannessen, 1983; Andersen, et al., 1983)

CHAPTER 5

LEGAL AND ADMINISTRATIVE PERSPECTIVES ON RISK ANALYSIS IN THE OCS CONTEXT

5.1 INTRODUCTION

Risk analysis undertaken in the context of offshore development can be useful to a number of actors, each of whom will approach it differently. Thus, risk analysis for public decisionmaking is directed at a different set of risks from those of primary concern to private decisionmakers, even though there is substantial overlap between the two. Similarly, an assessment of environmental risks requires different information and techniques from an analysis of health risks to workers.

Nevertheless, risk analyses, however applied and in whatever context, contain common aspects that would make their increased use a significant modification to existing decision processes. These include the increased formality risk analysis brings to decisionmaking, the increased use of quantitative and probablistic analytical techniques, a greater emphasis on safety as an issue of concern, and a more explicit articulation of the trade-offs implicit in decisions where risk is an important factor.

The discussion in this chapter portrays the context - legal, institutional, and technical - into which risk analyses relating to OCS development fits. It maintains that developments in the legal and political climate have increased the need for and usefulness of risk analysis to both the private and public sectors, and it suggests some areas in which an expanded role for risk analysis might be appropriate. The chapter first reviews several important developments in the broader legal context that may influence how risk analysis will be used in the future. Then, it discusses specific ways in which risk analysis might be used in executing the missions of MMS.

5.2 THE LEGAL CONTEXT FOR RISK ANALYSIS

5.2.1 Public Law and Risk Analysis

The actions of public agencies that make decisions involving risk or risk analysis are governed by two principal sources of law: the specific statutory mandate under which the agency is operating, and the general body of administrative law relating to agency decision-making procedures and analysis. The following discussion surveys very briefly some of the most important recent developments in each of these areas of law and considers their applicability to risk analysis relevant to the OCS context.

Different regulatory statutes have conceptualized and dealt with the issue of environmental, health, and safety risk quite differently. Thus, the legislative framework can in some instances require the regulatory agency to perform risk assessments and evaluate them in a risk-benefit framework. In other instances, risk analysis may be discretionary on the part of the agency. Similarly, quantification and description of risk may in some instances be the central issue in agency decision-making whereas in other circumstances it is peripheral, only one of many factors to consider. One can categorize regulatory systems into fundamentally different approaches. These include:

1. health-based regulatory systems - those whose overriding purpose is to protect public health or safety, thus requiring justification of regulatory actions in terms of their impacts on public health goals,

2. technology-based regulatory systems - those whose standards are based on a determination of available technology rather than environmental, health or safety impacts,

3. risk-benefit regulatory systems - those that explicitly call for a tradeoff analysis as the basis for decision-making, and

4. managerial regulatory sytems - those whose functions include both promotion of an economic activity and regulation of its potential adverse effects.

The two most noteworthy health-based regulatory systems are those established to limit air pollution under the Clear Air Act (CAA) and to protect occupational safety and health under the Occupational Safety and Health Act (OSHA). In the CAA, for example, the provisions on ambient air quality require that standards shall "protect public health, with an adequate margin of safety." This mandate has been interpreted to mean that questions of economic cost or technological feasibility are irrelevant to EPA's determination of an acceptable ambient air quality level. Since, under this statutory scheme, public health risks are the central concern, in order to justify its regulatory actions, EPA has had to perform detailed risk analyses of the hazards it has sought to limit[1].

The approach under OSHA begins with a similar health-based purpose - to protect all workers from material impairment of their health or functional capacity - but tempers this health goal with considerations of "feasibility." Thus, while the reduction of health risks is the principal goal, OSHA may only

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[1] Lead perhaps provides the best example of EPA's approach. Risk analyses have been performed of lead as a hazard in air, water, food, etc., and these have uniformly been reviewed and upheld by the courts. See Ethyl Corp. v. EPA, 541 F. 2d (D.C. Cir. 1975), cert. den. 426 U.S. 941 (1976) (lead in gasoline), and Lead Industries Association v. EPA, 647 F. 2d 1130 (D.C. Cir. 1980) (ambient lead).

pursue it to the extent that it is economically, technologically and administratively feasible. This framework has meant that OSHA must justify its regulatory actions both by a health-risk assessment and by an economic/technological analysis[2].

Technology-based regulatory systems are best exemplified by the Clean Water Act. Under this framework, standards for water pollution control are set by EPA on a sector-specific basis. Its decisions must be justified by a finding that technology available at reasonable cost is employed in at least some firms in the particular sector. Risk analysis is, therefore, not a necessary element of the decision-process, although it certainly could be employed if the agency found it useful.

Decision-making in other regulatory systems is based on an explicit risk-benefit analysis. By and large, these statutes tend to be later additions to the environmental, health and safety regulatory framework. Two are particularly noteworthy: The Consumer Product Safety Act (CPSA), and the Toxic Substances Control Act (TSCA), both of which require the regulation of "unreasonable risks" to the environment or consumer or worker health and safety. The interpretation of these statutes by the courts has made it clear that a cost-benefit framework is supposed to guide the determination of what constitutes an unreasonable risk[3].

Managerial regulatory systems are those which regulate safety or environmental hazards in a particular industry as well as the economic development of the industry. The airline industry (before deregulation of rates and entry) and the nuclear power industry provide perhaps the best examples. Typically, approval of plans or facilities must be based on a finding of "safety" by the agency. This legal necessity has led these agencies to employ probabilistic risk analysis to a very great extent.

The regulatory system implemented by the MMS, though perhaps closest in structure to the managerial system examples, contains aspects of several regulatory types. The emphasis on BAST as a regulatory instrument makes OCS decision-making similar in many aspects to that under the Clean Water Act. And the balance between MMS's need to protect the environment, health, and safety and its mandate to develop offshore resources expeditiously brings the analysis MMS may undertake closer to the risk-benefit/cost-benefit paradigm. This

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[2] See, for an early and prototypical example of the OSHA approach, Society of the Plastics Industry v. OSHA, 509 F. 2d 1301 (2d Cir. 1975) (regulation of vinyl chloride).

[3] For the CPSA see Gulf South Insulation v. CPSC, 701 F. 2nd 1137 (5th Cir. 1983), which deals with the regulation of urea formaldehyde foam insulation; and for the TSCA see EDF v. EPA, 636 F. 2d 1267 (D.C. Cir. 1980), which deals with the regulation of PCBs.

hybrid aspect makes the decisions concerning risk analysis from different regulatory areas of important relevance to offshore decision-making.

Three court cases considering risk analysis in the context of particular statutory mandates have been most important in defining judicial attitudes about this issue. The first case, Ethyl Corp. v.EPA, mentioned above, is important for its definition of risk (probability of harm multiplied by the severity of the potential harm), as well as for its strong statement that regulatory systems are intended to be "prophylactic" (i.e., to reduce risk). The court's approach implied a resolution of scientific doubt in favor of consumer protection, but it also recognized a strong obligation on the part of EPA to produce data and analysis in support of its decisions.

In International Harvester v. Ruckelshaus[4], where the court considered whether to allow a postponement of automobile emissions standards, the analysis of risk focused on both the risk of environmental harm and the economic disruption that would be caused by an overly strict regulatory standard. This approach was important because it recognized the need to balance incommensurable risks in the face of uncertainty. The court's finding that EPA had not adequately justified its refusal to postpone the emissions standards significantly enlarged the analytical requirements facing agencies as to the consequences of their actions.

The most recent important case, Industrial Union Department v. American Petroleum Institute[5], dealt with OSHA's regulations limiting worker exposure to benzene. Here, the court for the first time imposed a new analytical requirement on OSHA: the need to demonstrate a "significant risk" that would be reduced by government action.

Although none of these cases pertain directly to regulation in the OCS or MMS, they illustrate trends in judicial attitudes toward risk and agency decision-making that are relevant. Each of the cases is important for its insistence on an adequate evidentiary record to support the agency's decision. Indeed, they indicate that the judicial insistence on objective evidence has grown stronger over time. The second point to be made is that the judiciary has become more familiar with the concept of risk and the use of probabilistic evidence. Combining these two trends, one can discern on increasing acceptance in the judiciary of formal analytical methods brought to bear on the problems of risk management. These attitudes are likely to continue and be strengthened in the future.

Two more recent developments in public law are important, and both should have the affect of reinforcing the above-mentioned judicial attitudes. One action, taken by President Reagan in Executive Order 12291, requires a detailed

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[4] International Harvester v. Ruckelshaus, 478 F. 2d 615 (D. C. Cir. 1973)

[5] Industrial Union Department, AFL-CIO v. American Petroleum Institute, 448 U.S. 607 (1980).

analysis of the economic impact of major regulations before their promulgation. Although probabilistic risk analysis does not form a necessary part of E.O. 12291 analysis, the increasing formalism this order imposes on regulation is consistent with the use of risk analysis as well. The second development, legislative in character, may eventually result in a formal risk analysis requirement as part of regulation. This would occur if legislation considered by the Congress were to have passed. Even if none of these proposals is enacted into law, it seems likely that they will nevertheless encourage formal risk analysis in the agencies.

5.2.2 Private Law and Risk Analysis

At present, there are no doctrines or decisions from private law (i.e., tort and contract relationships among individuals and corporations) that impose a duty to perform formal risk analysis. Indeed, the term does not appear to have been used by courts in such cases. Nevertheless, trends in the development of both private and public law suggest that the acceptance of risk analysis by the courts may not be far in the future, and its use as an element in establishing legal liability not unlikely.

Tort law governing risk-laden situations is based in two theories: negligence and strict liability. Under negligence, liability arises when one party has failed to exercise "due care under the circumstances." Under strict liability, liability may arise without fault if a person engages in "abnormally dangerous" activities, or if a product used by a consumer is defective and unreasonably dangerous." Contract law between individuals (e.g., workers and employers) may impose any number of specific safety-related duties, but it is also usual for such contracts to include a "general duty" to keep workplaces "reasonably safe." These vague and general standards for determining legal liability are given precise meaning in specific circumstances where conflicts arise. A body of precedent thus arises which can inform conduct in the future. Several aspects of this body of tort law are particularly relevant to risk analysis and to risk management in offshore activities.

One concept of particular importance is the duty to test, inquire, and understand the hazards associated with products one sells or uses.[6] This duty has been defined and imposed most strongly in cases of worker exposure to toxic substances[7], but it applies generally. In the offshore operations context,

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[6] A major handbook entitled Products Liability, by Frumer and Friedman (Matthew Bender Co., New York, looseleaf, various dates), includes a lengthy treatise on the duty to inspect, test, and sample. See section 6.01.

[7] In Karjala v. Johns-Manville Corp. 523 F. 2d 155 (8th Cir. 1975), a leading case on this issue, the court imposed a duty to test in proportion to the potential for harm and a duty to keep abreast of the state of expert knowledge about product hazards.

therefore, the duty might be held to imply the need to understand the extent of the risk associated with such operations.

The duty to test is reinforced by the need to take precautions consistent with "custom" and the "state of the art." Custom, i.e., standard industry practice, frequently defines what kind of conduct is reasonable under the circumstances. Thus, for example, if the use of probabilistic risk analysis were not customary, it would be unlikely that a court would find the failure to use it as cause for liability. On the other hand, custom is never the ultimate measure. If, for example, the state of the art is such that safety measures (or analysis) could be employed at reasonable cost but are not being employed, a court may well base liability on such a failure to act.

Neither the duty to test/analyze safety risks nor the need to take preventive measures is absolute. Both are tempered by the probability of harm and the severity of the harm in question. Courts typically state that there must be a "reasonable anticipation of danger" before precautions need to be taken, or that a failure to act is not culpable when danger is "unlikely, improbable, or merely possible."

In sum, the standards of liability imposed by U.S. private law are highly flexible and particularistic, defined by the peculiar needs of specific situations. Custom and state of the art are persuasive measures of what constitutes appropriate behavior in such circumstances. Therefore, as an appreciation of the nature of risk and the techniques of risk analysis become more widely diffused throughout the public and private sectors, the use of such techniques as a measure of liability is likely to gain credence in the courts. Although U.S. courts tend to define best practice and reasonable conduct in a domestic context, the successful use of probabilistic risk analysis as a risk management strategy in leading multinational corporations overseas could also help to establish domestic legal norms.

5.3 MISSIONS AND FUNCTIONS OF MMS

The uses of risk analysis must be conditioned by the institutional context to which the analysis responds. Thus, for the MMS, any risk analysis activities must be compatible with the statutory mandates the agency executes, and will be most effective if they are compatible with existing MMS programs and operating styles. In generic terms, the MMS performs the following missions:

- formulating national resource policy
- developing regulatory standards
- issuing specific regulatory approvals
- monitoring and enforcing applicable requirements
- research and informational activities
- activities in support of industrial development

Within each category, a number of specific programs and activities are ongoing. The following discussion analyzes how issues of risk and risk analysis relate to these missions and functions of the MMS[8].

5.3.1 Formulating National Resource Policy

The broadest and most macro-level role of the MMS is to participate in formulating national policies for the development of resources on the OCS. The 1978 OCSLA amendments provide the framework for this mission and charge the Secretary of the Interior with responsibility for granting and administering mineral leases in the OCS. The statutory changes in 1978 made it clear that policies and procedures should be developed to expedite offshore development, while at the same time establishing environmental safeguards, assuring the safety of personnel, and preserving the resource base.

The MMS role in this regard may be characterized as custodial in nature. A host of complex factors - economic, technical, ecological, legal, etc. - enter into the formulation of policy, and many interest groups are involved: different industry groups, environmentalists, states and localities, etc. MMS, of necessity, becomes involved in balancing the various, and often-competing, interests and perspectives of these groups. In addition, however, as the lead federal agency with respect to offshore development, in formulating overall policy the MMS must play a coordinating role so as to ensure that the various governmental actors involved work efficiently in the national interest and not at cross-purposes.

More specifically, the resource policy formulation function involves MMS in a variety of information gathering, analysis, communication, and broad decision-making activities, which proceed in time from the initial consideration of offshore development through lease sales. These activities include gathering basic geologic, oceanographic, meteorological, and environmental data; selection of lease tracts; economic analysis of mineral resource exploitation, fishing, shipping and other uses of the affected ocean; safety-related analysis; the preparation of environmental impact assessments; the execution of memoranda of understanding with other agencies; and lease sales.

The type of risks with which MMS is concerned in formulating national resource policy are broad, general and systemic. Particular failure modes of engineered systems are not the principal focus of analysis within this

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[8] The Marine Board of the National Academy of Engineering in its recent report, Safety Information and Management in the Outer Continental Shelf, 1984, has categorized safety functions of the MMS somewhat differently. Their functional breakdown includes BAST, exploration and development, platforms, drilling, production, pipeline, enforcement, and accidents (see pp. 62-3). We offer a more generic categorization of MMS' functions in order to make them more relevant to risk analysis.

functional area, although they do constitute a relevant component. Environmental concerns perhaps present a prototypical example of the way the MMS must deal with risk in its policy formulation function. Here, the principal focus is on the nature and extent of overall environmental impacts incident to offshore development, and detailed analysis of environmental risks associated with particular activities serves as a data-base from which to address the more aggregate concerns. In the formulation of national resource policy, MMS is also concerned with the risks to national mineral resources, the risks to personnel and property engaged in offshore activities, the financial resources at risk in offshore development, and the risks to or conflicts with other uses of the ocean and coastal zone areas.

MMS' decisions in formulating national resource policy are likely to involve risk-benefit or trade-off analysis much more than engineering risk analysis. This is because the issues in controversy are mostly broad questions of jurisdiction or interpretation, not technical problems. For example, an important case recently decided by the U.S. Supreme Court[9] involved the balance between the national interest in development of the OCS and state perceptions of the environmental risks to the coastal zone. California had argued that lease sales by DOI should be subject to a "consistency review" to determine the impact on (i.e. the risk to) the state's coastal zone environment. The Supreme Court, however, has accepted the federal government's position that such a review is not needed until the exploration stage permits are under consideration.

Even within the confines of a mostly technical analysis, difficult policy questions of interpreting technical data face MMS. For example, there is currently controversy about the meaning of the risk analyses performed as part of environmental impact statements (EIS). Industry spokesmen have argued that the existing EIS's for offshore development in the Arctic should be regarded as presenting a worst-case statement of environmental risks there. (National Petroleum Council, 1981) In addition, the courts recently have tended to force worst-case scenarios on EIS analysis[10]. As a consequence of this focus on worst-case analysis in EIS's, MMS has available to it inadequate data for meaningfully quantifying a range of possible outcomes and their probabilities.

Because national policy formulation for the OCS is so complex and value-laden, increased use of the techniques of engineering risk analysis can

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9 Secretary of the Interior, et al. v. California, et al., 52 LW 4063 (Supreme Ct. Jan. 11, 1984).

10 In Village of False Pass v. Watt, 565 F. Supp. 1123 (D. Alas. 1983), a federal district court enjoined the Secretary of the Interior to re-do his EIS to take worst-case scenarios into account. The 9th Circuit Court of Appeals, in December of 1983, (Southern Oregon Citizens v. Clark, 720 F.2d 1475) commented approvingly on this decision and stated that the specification of worst-case scenarios and the probabilities of their occurrence is required in EIS analysis.

make at most only a modest improvement to the decision process. Nevertheless, attitudes toward risk and risk analysis articulated in formulating national resource policy have an important impact on the climate for use of risk analysis on a more disaggregate level

5.3.2 Developing Regulatory Standards

As part of its statutory mandate, the MMS has general responsibility for safety and environmental protection in connection with offshore activities. As one way of fulfilling this responsibility, the agency promulgates standards of operation for lessees on the OCS. In this regulatory standard-setting role, the MMS is the initiator of policies, rules, orders, etc. which are promulgated in accordance with procedures established by law. These regulations are of four general types:

- Lease stipulations,
- Specific technical requirements,
- Performance standards, and
- Systems safety policies.

In addition, the program to employ best available and safest technology (BAST - see discussion below) attempts to introduce improved technology into offshore operations on a continuing basis. All of these regulatory standard-setting activities are directly intended to reduce safety, health, and environmental risks.

Lease stipulations, which address unique risk characteristics of a lease sale area, are typically the most limited type of regulatory requirement emanating from the MMS. For example, in areas of the Beaufort Sea, seasonal drilling restrictions have been placed upon lessees in order to protect whales. A less formal, non-binding form of lease-specific regulation is contained in notices MMS gives to lessees with respect to particular new environmental, health, and safety concerns that arise from time to time. Not uncommonly, these notices are later formally incorporated as lease stipulations.

Specific technical requirements promulgated by MMS take the form of operating orders applicable to any of the four operating regions (Atlantic, Gulf of Mexico, California, Alaska). These orders provide detailed technical guidance with respect to virtually all aspects of off shore operations. Many of the MMS orders are based on or incorporate industry consensus standards, especially those of the American Petroleum Institute. The OCS orders are highly detailed and prescriptive with respect to the technical means of compliance.

Although these technical regulations have been developed with the intent of reducing specific known risks, there is some debate about their impact. One point of view is that the regulations may inhibit an operator's initiative to conduct risk analyses and to improve engineering and management practices on its own. One problem with the specific technical requirements is the need to revise the OCS orders frequently so as to keep pace with changing technology.

Performance standards promulgated by the MMS are generally identical in purpose to the specific technical requirements of the operating orders discussed above, but they are less detailed and specific. Typically, performance standards require use of general technologies or practices, or set performance goals. In either case, the operator has flexibility, within limits, to implement the compliance technique of his choosing. Many pollution control requirements are written as performance standards, as are, for example, the requirements for mud-pit level indicators, mud-volume measuring devices, and the like contained in Gulf of Mexico Order #2.

At the systems-safety level, MMS regulations may require the general technologies, procedures, or programs that a company must employ to reduce risk. For example, regulations require that operations not harm aquatic life[11], and that they be performed in a safe and workmanlike manner[12]. These systems safety policies are similar in some respects to the Norwegian "internal control" approach described in chapter 4 in the sense that they place responsibility on the lease holder or operator both to define the nature of the risks in question and to establish procedures to minimize them. To date, however, this approach is not used extensively in the U.S. as a means to reduce risk. The system safety approach relies on competent and conscientious analysis and action by individual companies. While it has the potential to be efficient and effective in some circumstances, the internal control approach leaves more discretion in controlling risks to companies than has generally been reflected in regulatory practice in this country.

In addition to these regulatory standard-setting activities, most of which have been in place for some time, the MMS administers the BAST requirement, which was enacted in 1978. BAST is both an informational/ analytical program and a regulatory requirement. In the former context, the MMS, through various data gathering and technical analysis activities, must keep abreast of the technological developments in industry. At least implicitly, the resulting determination of BAST technology for a particular application involves engineering risk analysis in order to determine the safety hazards associated with the particular component or system in question. After the BAST technologies are identified, it is then incumbent on the MMS to incorporate them into particular regulatory requirements. Programmatically, BAST has three components, the Technology Assessment and Research Program, BAST itself, i.e., applying BAST technology in the field context, and a BAST Certification requirement for operators offshore.

Because BAST determinations must be continually revised as new technology is developed, the regulatory requirements need to be similarly structured. However, the courts have not found that the regulations must incorporate the very latest technology at all times. This issue was raised in the case of

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[11] 30 CFR 250.43

[12] 30 CFR 250.55

North Slope Borough v. Andrus[13], in which plaintiffs argued that lease sales could not be held because BAST requirements had not been clearly specified for the technologies to be used there. The court, in rejecting this contention, described BAST as "evolutionary rather than fixed at any one particular time," thus allowing the government considerable leeway in its implementation.

5.3.3 Issuing Specific Regulatory Approvals

In addition to its missions of setting national policies and establishing standards of conduct, the MMS also undertakes a large number of review/approval activities. These cast the government in the role of respondent to industrial plans and initiatives involving applications for and uses of leased tracts. Because the MMS has over time developed a list of approvals necessary for OCS development and, in fact, imposes consistent technical standards on most of these plans, the approval role sometimes resembles standard setting. Nevertheless, there are differences both in the nature of the governmental function in the two instances and in the kinds of procedures and analyses that occur. These differences have important implications for the role of risk analysis in both the government and the private sector.

Various plans must be submitted to MMS for approval. These include exploration plans, development and production plans, applications for permit to drill, applications for installation of fixed drilling platform structures, platform verification plans, and oil spill contingency plans. The requirements of plan content are typically stated in general terms in regulations and may frequently refer to industry standards. The operator must demonstrate through his plan that operations will be conducted so as to satisfy these general performance standards. Thus, plans include detailed descriptions of, for example, the type and sequence of activities, proposed timetables, description of equipment, safety and pollution prevention measures, etc. (Marine Board, 1984)

The development and approval of these plans relates to risk analysis in several ways. From the MMS point of view, the choice of what types of information to require in plans could be guided by a prioritization of the most serious risks involved in the particular situation in question. Going further, it would be possible to require that information submitted in plans utilize risk analysis techniques for analysis and as a mode of presentation of anticipated risks and their control. From a company's point of view, the use of engineering risk analysis could assist in the approval process and affect its private liability situation as well (see discussion in section 5.2.2). Indeed, a number of companies now appear to conduct system safety analyses of their own[14]. Moreover, API recommended practices are also similar in content.

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[13] 642 F. 2d 589 (D.C. Cir. 1980)

[14] An excellent review of current practice is contained in position papers from a conference sponsored by the National Bureau of Standards, "International Workshop on the Application of Risk Analysis to Offshore Oil and Gas

Thus, the consistent use of some form of risk analysis in the planning/approval process need not represent a major departure from the current best practice.

5.3.4 Monitoring and Enforcing Applicable Requirements

The monitoring and enforcement functions of the MMS involve it in a wide variety of reporting/record-keeping activities, plan approvals, inspections, and legal actions against violators. There is considerable overlap in this area with other federal agencies.

The enforcement function - detecting, remedying, and/or punishing violations - is straightforward in concept, if difficult in actual practice. Its relationships to risk and risk analysis is indirect, consisting mostly in the possibility of feedback information from violation reports, which operators could use to identify particularly unsafe or harmful activities. Nevertheless, this feedback could probably be a more effective deterrent than it now is. For example, during 1971-75, when a public reporting system for oil spills was developed, the occurrence of accidental spills dropped dramatically: the number in 1975 was only 25% of the 1971 figure[15]. This suggests that public reporting of violations can be an effective deterrent.

The use of risk analysis in the monitoring/enforcement context would perhaps be most profitable if designed to prevent risk-laden situations or violations before they occur. One way of approaching this goal might be to tie the acceptance of lease bids or the frequency of inspections to past records of accidents or violations. To do so, however, would require substantial historical records.

5.3.5 Research and Informational Activities

The research, information-gathering and analysis activities of the MMS naturally cover a wide range of topical areas. Without question, the ability of the goverment to conduct a risk analysis of any kind depends, to an important extent, on the quality and quantity of information upon which the analysis may draw. Thus, well constructed information gathering and research programs are crucial to the development and use of risk analysis as a decision tool. Twice within the last few years, the National Academy has undertaken examinations of the information base upon which MMS decisions are made. In its earlier report, the following conclusions were reached:

- The OCS information base organization is complicated by lack of consistency among different agencies,
- The end uses of data collected are not always clear,

Operations," NBS, Gaithersburg, Md. March 26-27, 1984. (National Bureau of Standards, 1985)

[15] U.S. Geological Survey, Conservation Division, "Civil Penalties Instructional Memorandum," November 12, 1981.

- o Safety informational activities have not been adequately integrated,
- o Causal information about risks in inadequate,
- o FIRS shows promise as an information base, and
- o Accident investigations provide the best source of information about risks associated with conventional technologies. (Marine Board, 1981)

In its more recent report, the Marine Board (1984) made a number of specific recommendations for how the collection and measurement of OCS safety information might be improved. While the Board's report does not mention risk analysis specifically, it does note the lack of adequate procedures in MMS for analyzing safety data in a coordinated manner, especially to monitor safety performance.

5.2.6 Activities in Support of Industrial Development

MMS is somewhat unusual among governmental agencies that perform regulatory functions since, by statute, it is also charged with promoting the expeditious development of OCS energy resources. This implies the need for programs beyond the approval process to support industrial activities, On the one hand, such programs may take the form of an R&D effort that includes projects that, though useful to industry, are not being undertaken in sufficient numbers or scale. For example, in the past the MMS R&D program has focused primarily on safety-related applied research in the areas of structures, pipelines, well control, and environmental concerns. Similarly, information dissemination (e.g., Safety Alerts) or conferences to which industry is invited play an important supportive function.

A more complicated, but perhaps more important, approach to industrial support is to implement regulatory standard-setting, regulatory approval, and inspection programs so as to benefit industry while serving the broader range of public interests. This requires an appreciation of the circumstances under which the imposition of technical regulatory requirements can be made consistent with the technological and economic goals of industry. The BAST program may offer a unique opportunity to achieve this kind of complementarity. BAST is not intended to be a "technology-forcing" regulatory activity in the sense of requiring the development of new technology. Rather, its purpose is to encourage the diffusion of best practice throughout the industry. This, in principle, should contribute to both improved safety and efficiency. The use of risk analysis by both industry and government may be similarly beneficial if appropriately applied so as to achieve a balance between the value of the analyses undertaken and their cost.

5.4 RELATIONSHIPS BETWEEN MMS AND OTHER AGENCIES

A large number of federal and state agencies have jurisdiction over some aspect of OCS activity. In addition, a number of intermediary institutions - API, ASTM, ABS, ASME, etc. - have activities which relate closely to the MMS mandate. These agencies are concerned, to varying degrees, with problems of risk and risk management in the offshore context.

In the Department of Transportation, the Coast Guard and the Office of Pipeline Safety both regulate aspects of offshore safety. The Coast Guard's general authority, dating back some 100 years, is for the safe operation of vessels and floating ocean structures. A variety of specific mandates, including pollution control, inspection, and certification programs are contained within this broad authority. Memoranda of Understanding between the USCG and the MMS[16] and between the USCG and OSHA coordinate the activities of these agencies[17]. The Office of Pipeline Safety has jurisdiction over gathering lines and transmission lines offshore and on shore, whereas MMS exercises jurisdiction up to the flange connected to the transmission pipeline. EPA authority relates to the OCS under both the Clean Water Act and the Clean Air Act. In the water pollution context, EPA sets effluent standards and ocean discharge criteria. The Department of the Interior, however, regulates OCS air pollution. A recent DOI proposal would, if finalized, provide for a method of exempting various offshore structures from consideration of their impact on on-shore air quality[18]. Department of the Army (Corps of Engineers) authority over navigational obstructions covers artificial islands and fixed structures in the OCS and the safety of shipping that may come into contact with such activities. Among the federal agencies, the greatest degree of overlap with respect to risk management exists between MMS and the USCG.

The relationship between federal and state interests in offshore activities was explicitly recognized in OCSLA. Recently, controversy has emerged over the extent to which federal leasing activities need to take into account state determinations of their risks to the environment and other activities in the coastal zone. This issue has been addressed by the Supreme Court. In Secretary of the Interior, et al., v. California, et al.[19], the court held that a "consistency review" (i.e., between federal and state OCS and coastal zone interests) is not necessary for leasing activity. The court distinguished between lease programs and sales where the review is not required, and lessee exploration, development, and production, where consistency review is required. One effect of the decision is to postpone considerations of coastal zone risks until later in the development process. Another is to move more decisionmaking power toward Washington, D.C. and away from the states.

One area of institutional overlap that has not been emphasized is between U.S. offshore activities and those of other countries. Although the direct effects of offshore operations in one country on those in another are usually slight, there is nevertheless the potential for significant benefit from better coordination of international activities. In the area of risk analysis, for

[16] 46 Fed. Reg. 2199, January 8, 1981.

[17] 45 Fed. Reg. 9142, February 11, 1980.

[18] 48 Fed. Reg. 25837, June 10, 1983.

[19] Secretary of the Interior, ibid.

example, much more could be learned about attitudes and practices of other countries in both the public and private sectors. Similarly, exchanges of personnel and data gathered by government agencies could be valuable input to safety-related decisions. An increase in government-to-government contacts could be particularly beneficial in light of the increased internationalization of companies in the offshore industry.

CHAPTER 6

OBSERVATIONS, FINDINGS AND POLICY OPTIONS

6.1 OBSERVATIONS

6.1.1 Offshore Risk Management in the U.S., the U.K., and Norway

All three of the countries we studied have debated the proper relationship between the agencies charged with the responsibility for overseeing the development of offshore energy resources, and the agencies concerned with managing its risks. In each country, the specialized nature of the technologies, the limited number of government employees expert in them, and the costs and difficulties of physical access to offshore facilities have been used as arguments for combining the two sets of responsibilities in a single agency. However, in each country questions have been raised about whether an agency that is charged with leasing the resource for development can be counted upon to vigorously enforce risk management requirements. For example, the Burgoyne Committee in the U.K. was established principally to determine whether the Department of Energy or the Health and Safety Executive should oversee offshore hazard controls, while in Norway a similar conflict arose between the Petroleum Directorate and the Ministry of Labor. In each case, the outcome has been some combination of both functions in a single agency.

In each country, the system for regulating the safety of offshore structures and operations has evolved from the long-standing system for regulating the safety of vessels. For example, both the U.K. and the U.S. vest the proximate authority for assuring the integrity of offshore structures, both fixed and mobile, in the hands of non-governmental certifying agents, as is the traditional approach for vessels. More recently, however, Norway has taken a different course. For fixed structures, Norway has abandoned the certifying agent system and has adopted a form of "internal control" that imposes the responsibility for risk management directly on the operating firm. Each operator is required to adhere to a series of procedures that cause the firm to pay attention to safety and environmental concerns at every step of design, construction and operations. Now, Norway is close to adopting the same principle for floating offshore energy structures as well; a step that would mark a major break with traditional treatment of the safety of floating vessels.

As a consequence of the combination of developmental and regulatory functions in the same agency, the tendency in all three countries is for the regulators and the industry to see themselves as pursuing common goals. This tendency is reinforced in Norway and the U.K. by the critical dependence of their national economies on offshore oil for domestic supply, royalty income, and foreign exchange. In the U.S., on the other hand, offshore oil production and revenues have been relatively less important to the economy; a condition that has weakened the need for industry and government to seek a harmonious relationship. In more recent times, however, business-government relationships in the U.S. have become somewhat more positive, while offshore oil has become increasingly important. Thus, the foreign experience with offshore safety management is becoming increasingly transferable to the U.S.

The governments of all three countries support research and development (R&D) related to safer technologies for use offshore. In recent years, the Norwegians have mounted an ambitious offshore safety R&D program, motivated in part by the Ekofisk blowout and by the loss of the Alexander Keilland hotel platform. This program has supported research to advance the state of the art of risk analysis, to apply it to offshore problems, and to use risk analysis in setting R&D priorities. The U.K. government, which also funds research on offshore technologies, has supported a small number of offshore risk analysis studies, most of which analyze operational problems. The U.S. government, which supports a modest offshore technology research and development program in the MMS, supported two studies in the early-1970's on the potential use of risk analysis in offshore design and safety management. Only the Norwegians have adopted risk analysis procedures as a routine part of their safety management system.

6.1.2 Offshore Risk Analysis Experiences in Three Countries

In all three of the countries, lack of access to the details of most of the offshore risk analyses that have been done made it difficult to judge their quality and usefulness. Government supported studies in the U.S., which are public documents, have had only limited circulation. Company-supported studies done in the U.S. were not available to us. In Norway and the U.K., neither government nor company-funded studies are available, other than pilot and research studies and brief summaries of operational studies. Thus, our comments on the utility and quality of the studies of which we became aware are for the most part second-hand and are based heavily on interviews with their authors and users, and on a few published summaries.

In recent years, Norway has required operators to perform and submit a formal hazard analysis of proposed offshore structures with the "Main Plan", the document that is required before development of a new field or region can begin. This requirement, which is a major element in the implementation of the system of internal control, was adopted following a comprehensive risk analysis of an offshore system done for Statoil, the Nowegian state-owned oil company. Both the government and the operators appear to be pleased with this use of risk analysis, although some firms expressed displeasure that they were being required to perform this type of analysis.

The U.K. has no formal requirements for the use of risk analysis in the offshore industry. The regulatory authorities have commissioned pilot studies to provide a basis for understanding whether risk analysis might be useful. For example, preliminary studies have been done using event and fault tree methods to identify and analyze the areas of greatest potential hazard in a typical offshore production platform, and using a hazard and operability method to assess the safety of offshore diving operations. A probabilistic ship collision model has also been used to study the siting of fixed platforms off the southern coast of England where they might be placed near shipping lanes.

In the U.S., risk analysis has not been required for offshore energy activities. Following the recommendations of a panel of risk analysis experts from the National Aeronautics and Space Administration, two pilot studies of the use of risk analysis in the offshore arena were done with Federal sponsorship in the early 1970's. More recently, A.D. Little, Inc. (1982), under contract to MMS, has used risk analysis in an attempt to assess the benefits of offshore regulations. We were unable to get access to any reports, other than brief summaries, of privately-supported offshore risk analyses, and were thus unable to assess their utility.

However, attention has been paid in the U.S. to the use of structural reliability analyses in the design and evaluation of offshore structures. Such probabilistic methods are being used by a committee of the American Petroleum Institute to establish design criteria for platform structures. Another API committee has used a hazard and operability approach to develop a procedure for assessing the adequacy of fire prevention and hydrocarbon control devices on offshore processing equipment, which API has adopted as a voluntary standard. Many U.S. operators believe that such applications represent the best use of probabilistic methods in platform design at the current time, while other observers suggest that more could be done to supplement existing design and analysis approaches with other risk analysis techniques.

6.2 FINDINGS REGARDING THE USE OF RISK ANALYSIS OFFSHORE

As a consequence of our research, we have made a number of observations regarding the circumstances and implications of the use of risk analysis in offshore risk management. This section summarizes some of our more important findings.

First, several recent judicial decisions have strengthened the need for both industry and government to analyze proposed actions that may adversely affect workers and the environment. Judicial decisions reviewing public agency and private decision-making continue to endorse quantitative analysis as a means of rationalizing actions taken, or not taken, to control environmental, health, and safety hazards. In addition, court decisions on private liability suits focus on the preventability of forseeable hazards, thus increasing the need for firms to apply probabilistic analysis to potentially dangerous situations.

At the same time, presidential executive orders have required agencies to make regulatory decisions so as not to unduly burden industry and the economy. Such statutes as the Regulatory Flexibility Act and the Paperwork Reduction Act direct agencies to regulate in the least burdensome way. Furthermore, Congress is considering a statutory requirement that agencies do regulatory analysis when they issue new or revised regulations. Indications are that such pressures to do analysis prior to engaging in hazardous activity will continue to grow, especially as the state of the art of such methods is improved. Risk analysis may offer a useful approach for doing such required analyses for offshore activities.

The most complex and comprehensive version of risk analysis may not always be the most useful or appropriate. In fact, experience to date suggests that more limited approaches may be more useful in some circumstances. For example, hazard and operability studies to identify major risks on a production platform that might have been overlooked during the conceptual design phase may be more cost/effective than full-blown, large-scale, fault and event tree studies. Similarly, rules of thumb and general design criteria developed by special study teams using probabilistic approaches to structural design or to safety system evaluation may be more useful than comprehensive structural or system assessments in routine engineering activities.

In most applications, the use of risk analysis has tended to focus the attention of analysts and decision-makers on low-probability, high-consequence events, and thus to create a bias toward preventing extreme events rather than controlling the everyday accidents that also cause substantial loss in the aggregate. While this outcome of the use of risk analysis is not inherent in the methodology, the practical limitations of analyzing complex systems at the level of detail needed to uncover routine events, along with the problems of aggregating more than one category of loss simultaneously, have led to this bias. Thus, risk analysis is no substitute for a good program to manage the ordinary workplace and environmental hazards of offshore activities.

For example, the risk analyses done in Norway focus almost exclusively on the prevention of fatalities. The studies emphasize such catastrophic events as loss of well control with subsequent fire, or the total failure of an offshore structure. It is tacitly assumed that this approach to major hazard control will also tend to control the injuries that might arise from the same events, as well as from other events that are not generally life-threatening. It is not at all clear that this outcome will occur, however, since many disabling injuries arise from routine slips, falls, dropped objects, and the like.

In view of the bias of risk analysis toward catastrophic events, it is unreasonable to expect that it can substitute for more traditional types of safety and environmental management studies. On the other hand, traditional personnel safety and environmental control analyses are inadequate for addressing most catastrophic losses, and the two approaches can best be viewed as complements, not substitutes. In fact, in some companies, systems safety and personnel safety are organized as separate functions under different managements.

A major requirement for doing risk analysis is the availability of a data base on the performance of systems and components in the field. To date, the shortage of such data is a major barrier to further implementation of risk analysis. It is frequently necessary to make use of data on components used in radically different industries or environments, or to substitute expert judgment for actual data on component performance. While using poor or inadequate data is probably superior to using no data at all, there is a recognized need for more and better data both in Europe and the U.S. Currently, the Norwegian OREDA (Offshore Reliability Data) project is gathering such data on a voluntary basis from operating companies in the North Sea. The only such system in the U.S., the now-defunct Failure Inventory Reporting System (FIRS) of the USGS, was generally believed to be unsuccessful and was cancelled in 1981. It may be useful to consider reestablishing such a component data collection system in the U.S., perhaps under the auspices of an industry organization and with the assistance and participation of the regulatory authorities. It is generally thought that the success of OREDA can be attributed in part to the fact that it is a voluntary effort and is not carried out under a formal mandate from the authorities.

The use of formal methods of analysis, especially those as complex as risk analysis, challenges the abilities of non-technical groups with interests in offshore activities such as labor organizations, environmental groups, and state and local governments. Such groups rarely have access to the technical expertise necessary to perform, critique, or participate in studies that require expert knowledge, even though they have a legitimate interest in doing so. Thus, the technically-rich organizations that do the studies should ensure that their methods, assumptions and results are made widely available to the public in understandable form. At the same time, interest groups need to try to cope with the new methods of analysis, which can be expected to be used more widely in the future.

While risk analysis is a set of methods for analyzing complex systems in the presence of uncertainty about their environments and their performance, its use does not necessarily lead to a more certain set of outcomes, or to an improvement in the nature of the outcomes. The models of systems and the interactions of their components with which analysts must work are nearly always incomplete and uncertain, regardless of the quality of the data on which they are based. Like all types of quantitative decision methods, risk analysis is subject to the fallacy of "misplaced concreteness", wherein the consequences that can be quantified take on exaggerated importance relative to those that must remain more qualitative.

Thus, risk analysis should not be allowed to substitute for the informed judgments of professional operators, managers, engineers and accountable public officials whose jobs require them to consider the full range of public interests when making design, operation, and regulatory decisions.

The Norwegian system of "internal control" is an interesting model for an offshore regulatory scheme. Under this approach, operators must fulfill a set of overall procedural requirements for safety management that substitute for the establishment and oversight of detailed design and operating rules by regulatory authorities and/or third-party certifiers. As implemented in

Norway, as compared with older approaches to regulation, this system involves substantially less day-to-day oversight of company operations by regulatory authorities, while it strengthens the accountability of operators for the consequences of their activities. Fewer regulations require fewer regulatory staff than are needed if every installation is directly supervised by government representatives. Under the Norwegian system, all offshore designs and operations remain subject to random spot checks by authorities. Formal analysis of risk plays a key role in determining whether a proposed design is in compliance with the overall levels of acceptable risk that are promulgated by the Norwegian Petroleum Directorate. Finally, the workers on an installation in Norwegian waters have a legal right to be represented by an elected ombudsman who is in a position to bring safety problems to the attention of the operator and/or the authorities if need be, and who can even require activities to halt if extreme hazards exist.

6.3 POLICY OPTIONS AND RECOMMENDATIONS

Our studies of the potential and the limitations of using risk analysis in offshore safety and environmental management suggest certain policy options for consideration by the Minerals Management Service, private operators and other parties interested in offshore activities.

Private operators in the U.S., such as oil companies, drilling contractors, equipment designers, and system fabricators may wish to consider expanding their use of probabilistic methods for analyzing the hazards of new systems that they propose to use. This practice should help make their designs and operations safer and less costly in the long run, both for themselves and for workers and the environment. Equally important, publishing the assumptions, methods, and results of such studies could help allay public concerns about offshore hazards. Also, the performance of such studies, combined with actions to ameliorate any problems that are identified as important, may help to defend against private suits brought by parties seeking compensation for injuries arising from offshore activities.

Other parties with an interest in offshore safety, such as labor unions, environmental organizations and state and local governments, should be alert to the opportunities and potential problems that greater use of formal methods of analysis may present to them. On the one hand, such sophisticated methods of analysis put them at a disadvantage if they attempt to intervene in proposals for offshore development. On the other hand, if used properly, such methods offer the hope of better control of low-probability, high-consequence events of the sort that so often motivate opposition to particular offshore or other major projects. It is important for such groups to learn how risk analysis works and how it is used, so that they may become informed participants in and critics of its use.

Risk analysis is potentially useful in a number of the functions and activities of the Minerals Management Service. However, it is not a panacea for the management of any aspect of offshore development or safety control, and it should be considered for use with full awareness of its strengths and limitations.

First, there appears to be little basis for imposing a requirement on operators or other parties that they carry out formal risk analyses of all proposed projects on a routine basis. Instead, at the current state of the art of the technique and of its practice in the United States, risk analysis is a tool that may be best reserved for use in unusual circumstances. For example, MMS might consider requiring that a thorough risk analysis be done for major applications of new and untried technologies, or for new projects in especially hazardous and uncertain circumstances, such as ones where weather conditions are poor, subsurface formations are untested, or there is an unusual potential for conflict between energy development and other uses of the adjacent ocean.

MMS could play an important role in supporting the development of capability to do offshore risk analysis and in nurturing a better understanding of its potential and limitations by, for example, sponsoring workshops, research and pilot projects, and other studies of methodologies. It might be useful to choose one area in which substantial development is underway or contemplated in the near future and to fund one or more pilot projects there, in cooperation with industry or other affected parties. For example, the overall strategy for leasing off the California coast might be improved as the result of studies of the conflicts between development and shipping lanes in the region. The results of such a study could be used to guide MMS's own priorities for the region.

In addition to supporting R&D on risk analysis methods, MMS could consider using these methods to help set its own R&D program priorities. While risk analysis results alone are insufficient for choosing final R&D program priorities, experience with this process in Norway suggests that it can be quite helpful in refocusing an existing program on important areas and in identifying new areas that may warrant R&D support.

Risk analysis can also be used in helping to set priorities for enforcement of existing regulatory requirements related to safety and environment and for establishing new regulations to address newly-discovered problems. For example, MMS could use a comprehensive risk analysis to determine whether such new approaches as tension leg platforms or guyed towers pose unique new hazards, and, if so, to choose the particular hazards on which attention should be focused.

Risk analysis appears to be especially useful in reexamining certain existing regulatory requirements to determine whether they are achieving their goals. For example, we learned of one case in which a Norwegian analysis of the risks associated with the mandated presence of a stand-by ship for North Sea platforms showed that the overall risk would be lower if such ships were not required, since the occupants of the stand-by ships themselves were exposed to hazards merely by their presence. It was determined that total risk would be lower if the ships were moved to port and dispatched to the site of a platform only when it was known to be in difficulty. This kind of comparative analysis of similar risks is an area in which risk analysis can be used effectively while larger questions of the distribution of risks among various groups can be set aside.

MMS might also consider enhancing its on-going technical cooperation with such organizations as the American Petroleum Institute and the American Society of Civil Engineers which are currently concerned with probability-based design methods for offshore structures. As voluntary design guidelines are developed by API or ASCE, MMS may wish to consider updating its own requirements to reflect the new analytical approaches. The Coast Guard is in the process of doing this for some of its offshore regulatory requirements.

At the current time, perhaps the most important option for MMS to consider is to enhance the general level of understanding of the potential and limitations of risk analysis for offshore applications, both within MMS and in all of the groups that have an interest in offshore safety management. It should be recognized that such understanding will be required not only in the operating companies but also in MMS itself and in the other groups that are involved. It should be noted further that risk analysis is not just another technique of analysis like others that good engineers use: because it is based on an analysis of probabilities it involves an entirely different mind-set from the deterministic methods that are traditionally used. It is the willingness to accept the facts that nearly anything can happen at some level of probability, but that not all such events are equally probable or equally damaging that is prerequisite to making effective use of risk analysis to help reduce the undesirable consequences of offshore activity.

Finally, in the longer-term, MMS and the Congress may wish to consider more far-reaching changes in the regulatory system that would take advantage of the power of formal analysis. Used properly, risk analysis can allow for more effective regulation of safety and environmental risks, while allowing industry greater flexibility in the selection of technology and operational methods, and while assigning more of the responsibility for the effective control of hazards to the operating companies. This might be done by adapting the self-regulation approach known in Norway as "internal control", or by requiring that operators adopt a formal program of quality assurance. One way to make such a sweeping change in the regulatory approach now in use would be for Congress to amend the Outer Continental Shelf Lands Act of 1978 to give MMS this explicit authority. Effective use of the method of internal control requires that the government specify the level of risk that it will deem acceptable for offshore activities in order to provide a a target for demonstration by operators that they have taken the steps necessary to design an acceptable system and operating plan. Establishing a level of acceptable risk has proven to be quite controversial in Norway for offshore regulation and in the U.S. for regulating such technologies as nuclear power. Whether an acceptable level of risk could be established for offshore activities in the U.S. remains to be determined.

APPENDIX

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Potential Applications of Risk Analysis in the Management of Offshore Petroleum Activities

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